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Recovery of Lime and Magnesium in Potable Water Treatment

Johnson County Water District No 1, Kans

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A hard, turbid surface water was successfully treated using the magnesium carbonate process in a 2 mgd pilot plant at the treatment works of Water District No. 1 of Johnson County, Kansas, for one year during 1975 and 1976. During this study, froth flotation was used to separate river sediments from calcium carbonate formed in the treatment process. Both bench-scale and pilot plant flotation tests have shown that sludges formed by softening turbid waters can be processed to yield a relatively pure calcium carbonate suitable for lime recovery. Prior to this work lime sludge from surface water treatment had not been useable for lime reclamation. Process variables affecting both magnesium carbonate recovery and calcium carbonate beneficiation were studied in this work. Magnesium carbonate was successfully produced on a continuous pilot scale from recycled magnesium bicarbonate liquor. Process economics were favorable. A comparison of capital and operating costs for magnesium carbonate treatment, sludge flotation and lime recovery with present operating costs, including waste disposal, indicated that annual costs would be lower with the new technology.

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RECOVERY OF LIME AND MAGNESIUM IN POTABLE WATER TREATMENT

by

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Grant No. S803194-01-4

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water and a spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment and management of waste water and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social health and aesthetic effects of pollution. This publication is one of the products of that research, a most vital communications link between the researcher and the user community.

The research reported herein was directed to the reduction of sludge discharges from water plants practicing lime softening and coagulation. Sludge reduction is accomplished by recovering the required water treatment chemicals; carbon dioxide, magnesium carbonate, and lime. The study reports that chemical recovery cost effectively eliminates an average of 85 percent of the sludge discharged from these types of water treatment plants.

Francis T. Mayo, Director
Municipal Environmental
Research Laboratory

ABSTRACT

A hard, turbid surface water was successfully treated using the magnesium carbonate process in a 2 MGD pilot plant at the treatment works of Water District No. 1 of Johnson County, Kansas, for one year during 1975 and 1976. During this study, froth flotation was used to separate river sediments from calcium carbonate formed in the treatment process.

Both bench scale and pilot plant flotation tests have shown that sludges formed by softening turbid waters can be processed to yield a relatively pure calcium carbonate suitable for lime recovery. This significant breakthrough is important for existing lime softening plants having a serious waste disposal problem, as to date lime sludge from surface water treatment has not been useable for lime reclamation.

Process variables affecting both magnesium carbonate recovery and calcium carbonate beneficiation were studied in this work. Magnesium carbonate was successfully produced on a continuous pilot scale from recycled magnesium bicarbonate liquor. The cost per ton to produce relatively pure MgO was estimated to range from $147 to $185. As in previous studies, water treatment efficiency offered by the recycled magnesium coagulation was found to equal or exceed conventional lime softening.

Process economics were favorable. A comparison of capital and operating costs for magnesium carbonate treatment, sludge flotation and lime recovery with present operating costs, including waste disposal, indicated that annual costs would be considerably lower with the new technology. When the facilities are operating at full design capacity, greater than $260,000 per year in savings is projected.

This report was submitted in fulfillment of Project Number S803196-01-4 by the Water District #1 of Johnson County, Kansas, under the partial sponsorship of the Environmental Protection Agency. Work was completed as of July, 1976.

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SECTION I

INTRODUCTION

In 1946 the American Water Works Association appointed a committee to study and report on the disposal of wastes from water purification and softening plants. That committee published six reports, the first in 1947 and the last in 1953.

The 1953 report of the committee noted that more than 96% of 1,530 reporting plants discharged sludge to streams or lakes without treatment and only 3% discharged sludge to drying beds. The report concluded with the prediction that there would be an increasing trend toward the enactment of state and federal laws to prevent water pollution.

In 1969 a new and larger committee of AWWA held a two-day meeting in New York City to present and discuss a full and in-depth study of this problem which has assumed serious proportions. In the words of the committee, "The water utility industry must now take action to solve its problem of waste disposal."

The 1973 Inventory of Municipal Water Facilities (not yet published), identifies some 7,539 municipal water treatment plants producing a total of 44,217 MGD, that use treatment processes which require waste discharge. In 1967, the Census of Manufacturers (2) reported a total of 6,087 industrial water treatment plants, producing 12,178 MGD that produce similar waste discharges.

Data collected and Supplement B of the Draft Development Effluent Guidelines for the Water Supply Industry (3) indicate a total sludge production from these plants of approximately 3 million tons/year on a dry solids basis. Of this total, approximately 1.5 million tons are produced from water softening processes. PL 92-500 identifies Water Supply as an industry, and as such, water plants must treat waste discharges to meet established guidelines for Best Practical Control Technology set for 1977, and Best Available Control Technology set for 1983. Considerable interest therefore, has been given to alternative means of sludge treatment.

Efforts to date have been predominantly aimed at sludge dewatering and hauling to landfills, with the available technology requiring considerable economic and energy expenditure. In many cases, landfilling dewatered sludge merely translates the problem from waterborne pollution control to solid waste management.

The efforts of the study reported herein were directed to the reduction of water plant sludge problems by recovering the very chemicals used to treat the water. Utilizing new water treatment technology to treat 2-5 MGD of water, studies were conducted to recover lime and magnesium compounds from the sludge produced. The study took place at the Tom C. Hansen Water Treatment Plant of the Water District No. 1 of Johnson County, Kansas, located near the Kansas River.

Study Description

Although primary study emphasis was directed to the recovery and purification of calcium carbonate from the sludge produced, considerable attention was given to evaluating the water quality obtained. Comparisons were made between the settled water produced by the pilot and the conventional plant. As the pilot plant settled water was mixed with the total plant production for pH stabilization and filtration, comparisons beyond the sedimentation process were impossible.

Surface and well water are utilized by the Johnson County plant although only Kansas River water was treated by the pilot facility. Raw surface water turbidities ranged as high as 1,000 JTU, with presedimentation reducing the turbidity in the water to be treated to a maximum of 150 JTU. The hardness was as high as 390 mg/l as $CaCO_3$ during a portion of the study.

Bench and pilot scale froth flotation studies were performed evaluating such process variables as: calcium carbonate particle size, pulp pH, temperature, residence time, silica, and collectors used. An attempt was made to optimize the process from both economic and performance considerations. The pilot plant operation and flotation studies were conducted over a 12-month period.

Magnesium carbonate trihydrate was produced from the recycled magnesium bicarbonate liquor in pilot scale. Bench scale unit process studies were conducted for all aspects of facility design for the flotation and magnesium recovery processes.

Objectives of the Study

The program for this study was planned with the following objectives as its goals:

1) Compare the effectiveness of conventional coagulation with recycled magnesium on a highly turbid surface water.
2) Evaluate the feasibility of recovering magnesium compounds from highly turbid surface waters.
3) Determine if froth flotation is a feasible method of beneficiation prior to recalcination.
4) Develop design information for all unit operations and processes involved.
5) Provide an economic analysis of each unit process or operation, and for the overall process.
6) Provide an overall process evaluation as compared with the existing process, including treated water quality and cost of sludge disposal.

SECTION II

CONCLUSIONS

- Treatment of a hard, turbid river water with the use of magnesium carbonate as a recycled coagulant produced results that equalled or exceeded those obtained with conventional treatment. Results obtained compared favorably with those from the Melbourne and Montgomery studies. Although the hydraulic loading rate on the water treatment unit under study was less than in the conventional plant, no difficulties would be expected with full-scale implementation of the process. The high pH of coagulation would eliminate the need for pre-chlorination, which should reduce the level of chlorinated hydrocarbons in the treated water.

- Froth flotation, using fatty acid collectors, is an effective, economical process for the beneficiation of calcium carbonate from water softening sludges. Studies conducted in excess of one year duration found that a minimum of 92% calcium carbonate purity could be obtained treating sludges as low as 65% calcium carbonate. Product recovery is anticipated to range from 85-90%. Optimum flotation conditions were found to be pH 9.0-9.5, Dresinate collector feed (TX-60W) 5-7 lb/ton, and little or no silica.

- Sludge recycle is necessary to increase calcium carbonate particle size for successful flotation separation. Generally, calcium carbonate with a D_{10} less than 2μ could not be floated.

- Froth flotation has been found to be successful even where low dosages of polymers and sodium aluminate have been fed. Sludge carbonation for magnesium removal is necessary prior to flotation.

- Froth flotation for calcium carbonate beneficiation will allow lime recovery from all softening sludges. Implementation will be dictated by the economics of lime recovery, initially limited to the larger water plants. Lime recovery will drastically reduce the objectionable water plant sludge for ultimate disposal.

- Recovery of magnesium carbonate trihydrate from the saturated magnesium bicarbonate recycle liquor was successful although the product recovered contained calcium carbonate, silica, and, to a lesser extent, iron. Laboratory studies indicated that the calcium carbonate and silica can be easily removed by satisfactory clarification. The cost per ton to produce relatively pure MgO was estimated to range from $147 to $185.

- Implementation of magnesium recycle, flotation, and lime recovery was found to be economically attractive for Johnson County. Recovery of magnesium compounds for sale should be delayed pending results of a market survey to be completed in the fall of 1976.

SECTION III

RECOMMENDATIONS

The results of studies reported herein demonstrate that incorporation of this technology offers advantages in water treatment efficiency, economics, resource and energy conservation, and reduction in sludge disposal requirements. It is therefore recommended that magnesium recycle, froth flotation, and lime recalcination be utilized by the Johnson County water treatment plant. It is further recommended that magnesium carbonate recovery for sale be delayed pending the completion of the marketing and economic feasibility study now underway sponsored by the City of Dayton, Ohio.

Froth flotation should be attractive for all coagulation-lime softening plants of sufficient size to consider lime recovery. Process economics must include sludge treatment and disposal for valid alternative comparisons. The size requirement is dependent upon the local conditions; however, generally in excess of 25 tons per day of CaO should be recoverable for the economics to be favorable. Additional studies should be conducted to determine if froth flotation can be successfully applied where conventional coagulants are employed in the coagulation-softening process.

Studies should be conducted to determine if froth flotation can be used to beneficiate lime-sewage sludges. Successful separation of calcium carbonate from calcium phosphate would have significant economic benefits for sewage plants practicing lime recovery. Proper combination of temperature and silica level may result in successful flotation separation.

Additional research is recommended to study the effectiveness of the magnesium process for the removal of certain heavy metals, asbestiforms (particularly chrysotile), and organic precursors.

SECTION IV

PROJECT DESCRIPTION

Water District No. 1 of Johnson County, Kansas

The Water District No. 1 of Johnson County serves some 14 municipalities in suburban Southwest Kansas City, Kansas.

Raw water is obtained from both shallow wells and the Kansas River, which has similar characteristics to the Missouri River. A partial chemical analysis of these raw waters is shown in Table 1:

TABLE 1. CHEMICAL ANALYSIS OF JOHNSON COUNTY'S RAW WATER

Constituent	Raw Kansas River	Settled River	Well
pH	8.3	7.9	7.2
Temperature (°C)	17	18	16
Turbidity JTU	100	30	8
Ca (mg/l as $CaCO_3$)	205	200	357
Mg (mg/l as $CaCO_3$)	59	59	67
Total Alkalinity (mg/l as $CaCO_3$)	188	173	301
Total Dissolved Solids (mg/l)	443	449	514
SiO_2 (mg/l)	12.7	13.3	27.9
Cl (mg/l)	84	89	65

1975 Annual Averages

Present treatment includes presedimentation, lime-soda ash softening of the blended well and settled water, use of polymers and alum for clarification, single stage carbonation, and high rate mixed media filtration. The present capacity of the well field is 9 MGD; however, the production is declining. Treatment plant capacity is designed for a maximum of 60 MGD with an average annual production of 22.5 MGD.

In 1975, maximum daily values for river water hardness and turbidity were 390 and 1,000 JTU, respectively. Maximum daily turbidity of the settled raw water during 1975 was 150 JTU. Presedimentation greatly reduces the turbidity loading to the water treatment plant; however, the suspended solids remaining are generally more difficult to coagulate. Treatment of this turbid, hard water produces in excess of 2,500 lbs of dry solids/MG of water produced. The predominantly calcium carbonate sludge, in excess of 11,000 tons/year dry solids, is presently dewatered in lagoons and hauled to a landfill at a cost exceeding $80,000 per year. As suitable landfill locations become more difficult to obtain, these costs are projected to increase dramatically.

Lime Recovery

Several water treatment plants, as shown in Table 2, have successfully produced high quality quicklime from their softening sludge. In every case, these plants treat water very low in suspended solids; thus, the sludge produced is relatively pure calcium carbonate. In recalcining water plant sludge, the calcium carbonate is converted to CaO as:

$$CaCO_3 \xrightarrow{\text{Heat 1700-2000°F}} CaO + CO_2$$

Sludge contaminants not volatized on calcination would increase in concentration as a result of the molecular weight difference between calcium carbonate and calcium oxide. Slaking problems have been reported when the calcium oxide purity drops below 80-85%. The lime impurities would also increase with recycle and reuse.

TABLE 2. WATER PLANTS PRACTICING LIME RECOVERY

City	Date Installed	Production[a] Tons/Day CaO	Type of Calciner
Miami, Florida	1948	90	Rotary kiln
Salina, Kansas	1954	-	Flash calcination
Lansing, Michigan	1954	16	Fluidized reactor
Dayton, Ohio	1960	92	Rotary kiln
Ann Arbor, Michigan	1968	8	Fluidized reactor
St. Paul, Minnesota	1968	25	Fluidized reactor

[a] average actual daily production

Recalcining operations at Dayton, Ohio, and Miami, Florida, have been notably successful. Dayton, Ohio, had sold more than $1,000,000 in excess lime by 1973.

When recalcining water plant sludge is compared with purchasing commercial quick lime, energy and resources are conserved. Typical operations required for commercial lime production and distribution require:

1) Mining of limestone or marble from quarry
2) Transporting to kiln
3) Crushing and grinding before burning
4) Calcination in kiln
5) Transporting in bulk shipment, frequently hundreds of miles

Recalcining of the water plant sludge would eliminate 1,2,3 and 5 of above. In addition, hauling of dewatered water plant sludge to ultimate land disposal would be eliminated. Energy requirements for the recalcination operation are similar for both commercial and on-site recovery operations. A large percentage of the energy used is lost either in radiant heat, or in the stack gases. Thus, the 35% or less moisture remaining in the dewatered water plant sludge does not add significantly to the energy requirements. Plants practicing magnesium recovery will utilize waste heat from recalcining, thus providing additional energy conservation.

Lime kilns designed prior to recent energy conservation efforts generally did not incorporate features that would reduce fuel requirements. As recently as the early 1970's, fuel costs as low as $6.00/ton of lime calcined were common. Dependent upon fuel source, this cost may today be as high as $20.00/ton. Lime kilns designed and constructed today incorporate a number of devices to conserve energy. Thus, regardless of whether the application is for recalcining water plant sludge or for a commercial limestone operation, energy requirements are lower than for the older installations.

Commercial lime operations reduce natural limestone reserves. Quarry operations leave unsightly terrain which one day may require restoration, further increasing energy requirements and lime costs. Lime production from oyster shells is coming under increasing attack by environmentalists as a result of the dredging operations required.

In the upgrading of calcium carbonate, or beneficiation, two parameters are of primary concern: the grade and recovery of final product. These parameters are termed simply grade and recovery and are generally expressed in percentage figures. The most commonly used scheme for beneficiation of calcium carbonate sludges, prior to recalcination, utilizes two-stage centrifugation. Centrifugation uses the specific gravity difference between the calcium carbonate and contaminant to make the separation. Rejection of magnesium hydroxide has generally been of primary concern; however, one recently completed investigation was directed to the separation of silt from calcium carbonate. (4) The primary disadvantage of this method is that considerable calcium carbonate is wasted with the contaminants in order to achieve an acceptable grade. Two-stage centrifugation has been employed on lime-treated sewage sludge to separate calcium carbonate from calcium phosphate. (5) Again, problems with recovery of calcium carbonate have been reported. Air classification following calcination has also been investigated for lime-sewage sludges with limited success reported.(5)

The product losses using these classification methods are necessary to prevent contaminant build-up on recycle. Product grade is generally not sufficient to allow reuse on a closed cycle system.

In 1957, Black and Eidsness (6) showed that the gelatinous, highly basic magnesium hydroxide could be rapidly and selectively dissolved from calcium carbonate by carbonating the sludge with kiln stack gas containing about 20% CO_2. This method has been successfully used at Dayton since 1958.

The recovery of both the calcium and magnesium values present in the Dayton sludge was described by Black, Shuey and Fleming in 1971 (7).

In the same year, Thompson, Singley and Black (8,9) found that magnesium carbonate recovered from such sludges may be used as a recycled coagulant for the treatment of most types of waters. The new technology may be summarized by the statement that all types of waters and many types of waste waters (hard or soft, clear, turbid or colored) may be treated by three chemicals normally present in such waters: calcium, magnesium and carbon dioxide. In so doing, the problems of sludge disposal are eliminated or minimized and chemical treatment costs significantly reduced.

The New Magnesium Process

A CAPSULE REPORT, "Magnesium Carbonate - a recycled coagulant for water treatment," (10) has been prepared and published by the Technology Transfer Division of the U. S. Environmental Protection Agency (EPA) which describes in considerable detail the application of the new technology for the treatment of various types of waters. The process has been previously studied by three different projects supported by EPA. (11,12,13)

The first was a laboratory study carried out at Gainesville, Florida, as EPA Project 12120 ESU, which was completed in May, 1971.

The second was a Demonstration Project, 12120 HMZ, conducted at Montgomery, Alabama, and Melbourne, Florida. At Montgomery, a pilot plant was constructed and studies made of the treatment of a very soft, turbid river water. The pilot study was followed by application of the process in the 20-MGD municipal water treatment plant, with one-half of the plant operated with alum as the coagulant and the other with a magnesium salt as the coagulant. The work was then extended to Melbourne, Florida, where a second plant-scale study was made of the treatment of a highly colored, low turbidity lake water. As at Montgomery, one-half of the plant was operated with alum as the coagulant and the other half with a magnesium salt as the coagulant.

The third project, EPA Demonstration Project 12130 HRA, was carried out at Gainesville, Florida, and was a laboratory and pilot plant study of the use of the new technology for the treatment of municipal and industrial wastes.

This, the fourth project of the series, differs in a number of respects from the earlier studies.

First, it has been carried out in a plant of major size treating one of the most turbid river waters in this country. The fact that the plant possesses a small "stand-by" 2 MGD Permutit Precipitator treatment plant complete with chemical feeders has provided the opportunity to treat a 2 MGD flow of the same water being treated in the large plant but with recycled magnesium bicarbonate as the coagulant. It was, therefore, only necessary to provide facilities for sludge storage, sludge thickening, sludge carbonation, magnesium recycling and recovery, and calcium carbonate beneficiation by froth flotation.

Second, it was possible for the first time to study froth flotation not only on a laboratory scale, but also in a continuous pilot plant operation.

Third, since this is the only water studied to date containing substantial magnesium, it has been possible to study magnesium recovery on an expanded scale. Such studies have been carried out previously at Dayton, Ohio, but with a clear wellwater relatively free from possible contaminants.

Froth Flotation

For a number of years, the mining industry has used froth flotation to separate valuable minerals from an ore slurry. It differs from dissolved air flotation, primarily in that the desired slurry components are selectively floated.

There are several different schools of thought regarding the basic mechanisms involved in froth flotation. Readers are referred to three highly regarded sources (14,15,16) for in-depth discussions. The present generally accepted theory appears to be that certain chemicals attract the desired minerals to an air-water interface provided by a bubble. This chemical, called a collector, attaches by its polar end to the mineral and its nonpolar end to a bubble interface. The bubble provides the needed air-water interface and physically carries the mineral particle from the flotation cell. The process is a highly sensitive system involving both physical and chemical forces.

In the flotation of calcium carbonate fatty acid collectors or their soaps are used. They are anionic materials having 18 carbons in the chain and are typically a mixture of oleic, linoleic, or resin acids, usually more effective in their soap form.

Frothers are chemicals added to promote abundant bubbles by lowering the surface tension of the water. They are used in many flotation circuits but are rarely needed when fatty acid soaps are used since these collectors are highly surface active and produce ample frothing.

Modifiers are used to activate or depress the action of collectors and generally provide greater selectivity. They range from sodium carbonate for pH control to a soluble silicate to depress or enhance calcium carbonate collection.

Since surface chemistry plays a major role in flotation technology, many investigators have utilized measurement of the zeta potential of the calcium carbonate particles in an attempt to increase process efficiency. However, as in water coagulation, the point of maximum efficiency is not always at the point of zero particle charge. It has been found, however, that in general, best collector efficiency is obtained if the charge is adjusted near zero. Zeta potential is, of course, affected both by change in the solution pH as well as by multivalent counter ions, present or added.

Froth flotation was patented in 1906. The first full-scale application in this country was in 1911, when it was employed at the Basin Reduction Company plant for the beneficiation of a copper ore. The first flotation circuits were mainly used for the separation of minerals naturally flotable, and required only frothers.

In 1926 froth flotation was first used to recover limestone from iron ore tailings using fatty acid collectors. In 1934, at Conshohocken, Pennsylvania, limestone was purified by flotation for the manufacture of Portland cement. (17) As late as 1960, only one plant in this country was reported to be using flotation for the benefication of calcite. This plant, operated by the Universal Atlas Cement Company, began operation in 1952, and presently floats about 1,000 tons of calcite per day. (18) In 1963, the Permanente Cement Company began floating about 2,000 tons of calcite per day. (19) It is reported that only one operator is needed to operate the flotation circuit and downtime the first year was less than 9%. In 1964, the Georgia Marble Company placed into operation a plant at Sylacauga, Alabama, floating 1,000 tons of calcite per day. (20)

Mined Versus Precipitated Calcium Carbonate

Frequently, terms used to denote or describe calcium carbonate are used incorrectly. Review of geologic terminology should assist in providing a better understanding of these commonly used terms.

"Rock" can be defined as a naturally formed mass of mineral matter. A mineral occurs naturally and is generally crystalline and inorganic in nature. Limestone is the predominant rock form containing calcium carbonate; however, marble is a rock consisting of crystalline metamorphosed limestone. Another rock, chalk, consists of finely grained pulverized calcium carbonate.

Calcium carbonate is found in nature in two mineral forms: calcite and aragonite. Calcite is the predominant mineral form of calcium carbonate. Aragonite is less common than calcite and much less stable. It will convert to calcite at elevated temperatures or in solution. It is generally formed at lower temperatures, near surface deposits.

A considerable degree of calcium substitution is possible. Calcite may have in excess of 10% magnesium subsituted as well as manganese, iron, and zinc. Generally, the degree of substitution increases with an increase in the rate of precipitation and concentration of foreign ions in solution. In addition to the substituted impurities, considerable impurities exist cemented between calcite crystals and layers of rock.

Calcite mined for cement or lime manufacture is most often obtained from the rock, limestone. The rock is crushed, generally to a size range of 100-200 μ, prior to flotation. Typical feed grade ranges from 80-85% calcium carbonate and only slight upgrading is required. Often flotation is preceded by wet cyclone desliming to remove much of the silt and fine materials.

Calcium carbonate found in water plant sludges is formed by the reaction of CO_2 and calcium bicarbonate with lime in very dilute solutions. Sheen and Lammers (21) state that the sludge produced by selective lime softening at the Wright Aeronautical Plant has an average particle size of 5-7 μ. Black (22) found that for a particle size distribution of sludge obtained in softening the water of Miami, Florida, where no magnesium is removed, 99% were finer than 24 μ, 72% were finer than 11.5 μ, and 30% finer than 4.9 μ.

A number of investigators have shown that sludge recirculation increases the kinetics of calcium carbonate precipitation and have suggested an increase in particle size. One study evaluated the effects of sludge recirculation on filtrability and thickening characteristics, indirect measures of particle size. With increased recirculation, the sludges thickened and dewatered much more readily. (23)

It is apparent, therefore, that the industrial flotation experience is not necessarily applicable to floating calcium carbonate from softening plant sludges, where the surface area is far greater due to the very small particle size. There is also the possibility, when calcium carbonate is precipitated in the presence of silt turbidity, that encapsulation of clay particles might take place, making separation by flotation impossible.

Of the several factors which control the flotation of calcium carbonate, particle size appears to be the most important. This is dramatically brought out in the studies to be reported. A method for the control of particle size is also discussed.

Calcite Flotation Theory

As stated previously, the pH of the sludge to be floated greatly affects the efficiency of froth flotation of calcium carbonate. Somasundoran (24) reports that calcite in an aqueous suspension with a pH between 9.0-9.5 usually has a zeta potential of zero. Most investigators have reported that fatty acid soaps are the preferred collector for calcite and that efficiency usually increases as the length of the collector chain increases. Maximum recovery is usually obtained in the pH range of 9.0-10.0.

As has been pointed out earlier, silica or a soluble silicate is often used to depress calcium carbonate collection. As the temperature of flotation increases, this depressant action of silica increases. The presence or addition of polyvalent cations is reported to increase the depressant action of the silica (25). Klassen (14) reported that $SiO_2=$ is less of a depressant than H_2SiO_2; thus higher pH flotation tends to reduce the effect of the silica.

It has been reported that additives which increase mineral hydration depress flotation, while additives which decrease hydration increase flotation.

At extremely high pH values, hydroxide ions compete with the collector, thus depressing recovery. The use of soda ash as a pH modifier has been reported to be more effective than sodium hydroxide.

To summarize the effect of particle size on the flotation of calcium carbonate, the smaller the particle size, the larger the surface area and more collector will be required. The particle size of freshly precipitated calcium carbonate is so small as to make flotation difficult. Anything which will bring about a significant increase in the particle size will greatly improve flotation efficiency. As discussed, sludge recycle for crystal seeding is an effective means of controlling particle size. Flocculation during flotation has also been used with success.

Several investigators have shown that carbon dioxide flotation of calcite increases collector efficiencies and thus reduces collector requirements. (26,27)

Higher pulp solids have been found effective in floating fine particles whereas lower pulp solids are more effective when large particles are present. There appears to be considerable controversy over optimum pulp density.

Froth Flotation with the Magnesium Process

The liquid phase of a fully carbonated sludge contains a concentration of magnesium ion from a low of a few hundred mg/l to as high as 3,800 mg/l.

The sludge is dewatered, removing as much of the liquid phase as possible. The sludge cake is reslurried, conditioned by the addition of flotation reagents and the slurry piped to the first series of cells referred to as the rougher. The float from the rougher, called rougher concentrate, is pumped to a second series of cells called the cleaner cells. The fraction of the pulp not floated is termed the tails.

Approximately 1.4 times more CaO is produced in water softening than is fed; therefore, 100% recovery in beneficiation and recalcination is not required for the process to be self-sustaining. The grade of CaO must generally be greater than 85% for proper slaking and feed. Therefore, from Figure 1, a 91% calcium carbonate grade feed to recalcining is required, assuming the impurity fraction is not reduced.

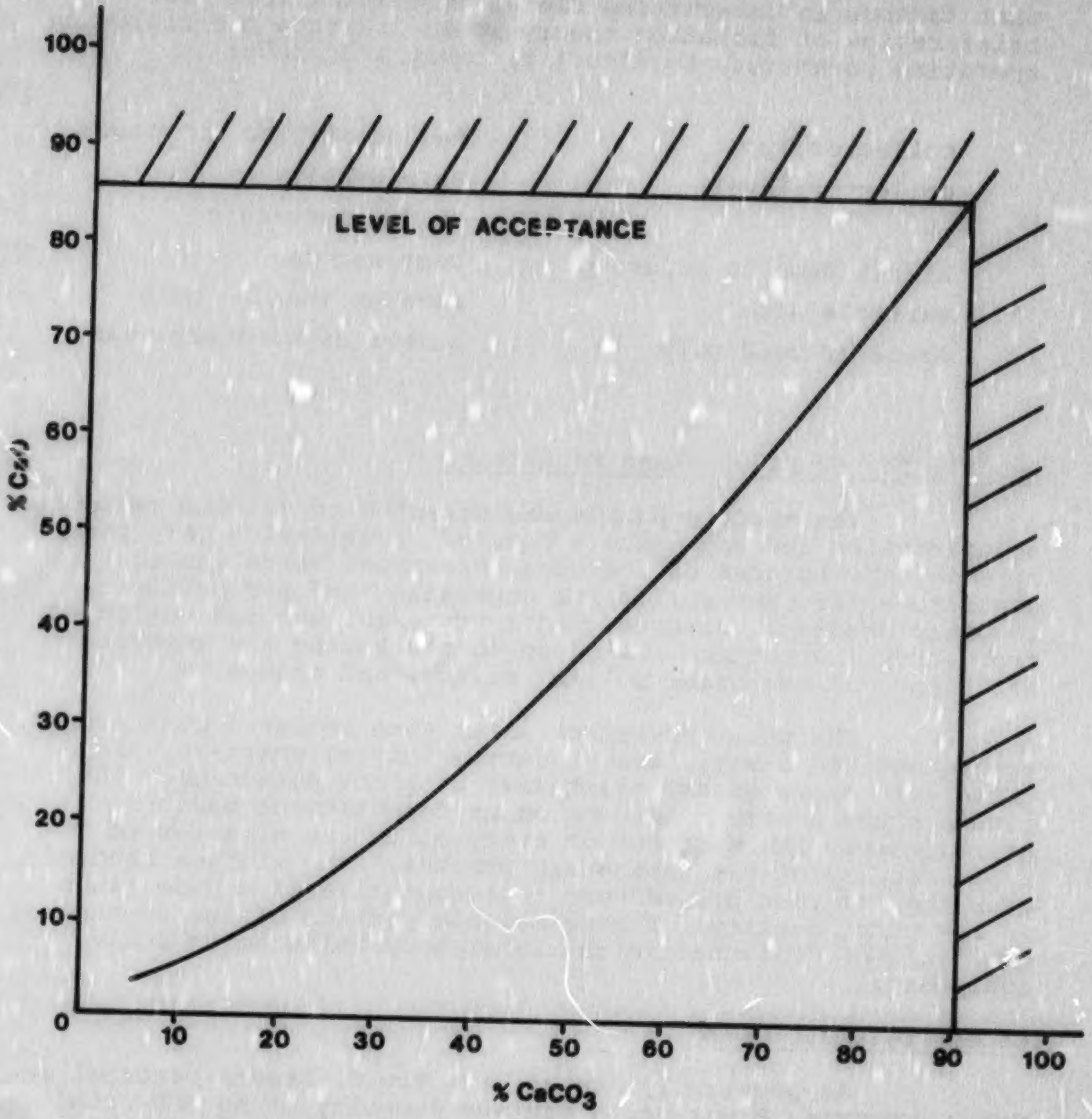

FIGURE 1. FLOAT $CaCO_3$ vs. CaO CONTENT AFTER CALCINING (Assumes no further beneficiation and contaminants nonvolatile).

Recovery and grade, therefore, are the two important factors in determining flotation feasibility. The brief review of flotation theory would indicate the following operating parameters to effect recovery and grade:

Collector type
Collector level
pH
Alkali used to adjust pH
Particle size
Grade of feed pulp
Residence time in stages
Pulp density
Pulp temperature
Depressants
Foreign ions in pulp
Number of cleaners used

Description of Pilot Plant Facilities

The study emphasis was directed to calcium carbonate beneficiation and magnesium recovery. Considering only these aspects, the purpose of the water treatment units was to generate sufficient solids for separation and production recovery studies. However, water treatment was not neglected from study. Attention was given to monitoring the removal efficiency of suspended solids, silica, and magnesium.

The water treatment units were operated continuously throughout the study. Except during initial start-up, these units were operated and maintained by plant personnel. The sludge studies were conducted on an intermittent basis. Approximately one week out of every month was directed to field studies of the separation process. The sludges studied over the one-year period were representative of a wide range in raw water quality. A considerable portion of the separation studies was conducted in the laboratory using bench scale equipment.

Water Treatment Phase

As previously stated, the Tom C. Hansen Memorial Water Treatment Plant has a maximum capacity of 60 MGD with a present average production 22.5 MGD. The original plant, constructed in 1956, utilized a Permutit Precipitator with a design capacity of 10 MGD. This portion of the plant was used in recent years only to meet peak production requirements. The study utilized one half of this facility along with the rapid mix and chemical feeders. Only minimal conversion was required. The settled water was mixed with the water from the other plant treatment units prior to stabilization and filtration. Therefore, following clarification, no study comparisons were made. Figure 2 illustrates the water treatment units discussed.

Table 3 summarizes the average chemical dosages fed in 1975, along with current unit costs. These data represent annual averages for treating well and river water. The treatment facilities allow raw Kansas River water, after presedimentation, to flow by gravity to the plant where river and well water can be combined in a desired ratio prior to treatment. During the study period, only settled river water was treated in the Permutit basin.

Prior to the study, settled river water turbidities often exceeded several hundred units. Careful presedimentation coagulant control has considerably reduced turbidities; thus eliminating the need for blending river and well water to reduce turbidity to desired levels during the study.

In the pilot operation, recovered magnesium bicarbonate was recycled to the rapid mix, and sufficient lime slurry fed to maintain a pH of 11.0-11.3. A number of investigators have shown that virus and bacterial disinfection occurs at this pH (28,29). The water then flowed approximately 30 ft through a flume into a 25-ft x 140-ft rectangular upflow precipitating basin utilizing internal flocculation and baffling. Precipitated calcium carbonate, magnesium hydroxide, and clay turbidity settled into V-shaped sludge collection troughs running the length of the basin.

Basin sludge was normally pumped to the carbonation cells at 8-10 GPM with a solids content of 5-10%. Carbonation to pH 7.0-7.2 was accomplished in four 10 ft^3 cells (Galigher #24 flotation cells[*]) with either pure or 18% CO_2, selectively dissolving the magnesium hydroxide into soluble magnesium bicarbonate. A 20-ft-diameter thickener was used for solids-liquid separation. Magnesium bicarbonate liquor flowed by gravity to the 1500-gal. storage tank prior to recycle to the rapid mix at controlled rates. A rotameter was used to measure recycle flows. The thickened sludge at 15-30% solids was normally pumped to the existing lagoon.

Sludge was collected by gravity using drilled pipe at the bottom of the V-shaped troughs. The thick sludge tended to plug the collection piping. A sophisticated back flushing system operating on a time cycle was used to reduce

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[*] Product of the Galigher Company, Salt Lake City, Utah

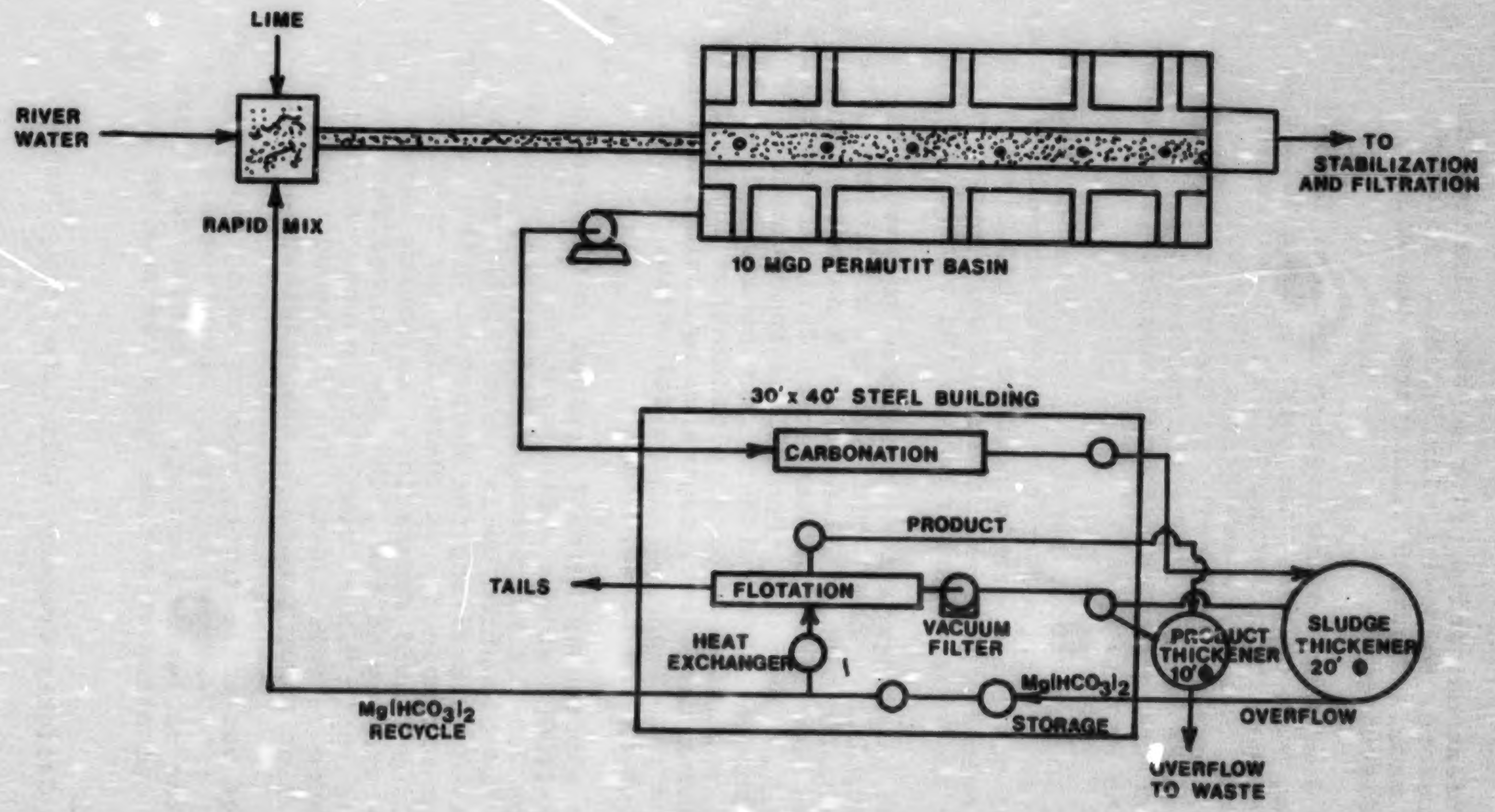
LIME
RIVER WATER
RAPID MIX
10 MGD PERMUTIT BASIN
TO STABILIZATION AND FILTRATION
30' x 40' STEEL BUILDING
CARBONATION
PRODUCT
TAILS
FLOTATION
HEAT EXCHANGER
VACUUM FILTER
PRODUCT THICKENER 10' ⌀
SLUDGE THICKENER 20' ⌀
Mg(HCO3)2 STORAGE
OVERFLOW
OVERFLOW TO WASTE
Mg(HCO3)2 RECYCLE

FIGURE 2. PILOT PLANT FACILITIES.

TABLE 3. 1975 AVERAGE CHEMICAL DOSAGES AND CURRENT COSTS JOHNSON COUNTY, KANSAS

Chemical	Dosage (mg/1)	Cost ($/Ton)
Chlorine		
Pre	5.4	200
Post	3.1	200
Alum		
Presedimentation	0.2	126
Plant	1.3	126
Lime	135.0	38
Soda ash	13.8	77
Sodium Aluminate	2.0	412
Polymer		
Presedimentation	0.9	898
Plant	0.7	898
Carbon Dioxide	20.4	38
Carbon	1.5	420
Potassium Permanganate		
Presedimentation	0.4	1234
Poly Phosphate	0.4	528
Fluoride	1.2	294

plugging problems. The system back flushed for a period of seconds, and the flow valved to waste to remove the clear water remaining in the pipe. When the timer was carefully set, little, if any, sludge was wasted; however, if out of sequence by only a few seconds, hundreds of gallons of sludge were wasted from the system. This loss of sludge represented magnesium lost from the system.

The level of the sludge blanket was maintained to not exceed a pre-determined maximum height. Sludge was wasted when this level was exceeded.

Flotation Circuit

During flotation studies a 3-ft-diameter by 1-ft-wide vacuum filter dewatered the thickened sludge, with the filtrate returned to the magnesium bicarbonate storage tank. The resulting filter cake, varying from 40-60% solids, was reslurried in two 1.5-ft^3 cells followed by two similar cells where flotation reagents were added. Diaphragm solution metering pumps were utilized to feed reagents from four 55-gal. chemical mixing tanks.

Flotation was performed in three stages, one rougher stage and two cleaner stages, with each stage consisting of four 1.5-ft^3 cells. Air was supplied at 6.7 cfm per cell (or 80 cfm to the flotation cells) by a centrifugal blower. A process flow diagram of the flotation circuit is shown in Figure 3. The conditioned feed flowed by gravity to the rougher cells. Rougher concentrate overflows the cells as froth is collected by launders and pumped to feed the first cleaner. The rougher tails, containing clay turbidity and calcium carbonate not collected, are wasted. The first cleaner concentrate is collected by launders and pumped to feed the second cleaner. The second cleaner concentrate is collected by launders and, in this case, is the final flotation product. The final product is pumped to the 10-ft-diameter thickener for storage. All cleaner tails flow counter current, where remaining calcium carbonate may be collected. The rougher tails were wasted to the sewer. Following each flotation study, the product could be dewatered for further evaluation using the vacuum filter.

The flotation circuit was capable of processing from 150-200 lb/hr of feed solids on a dry basis.

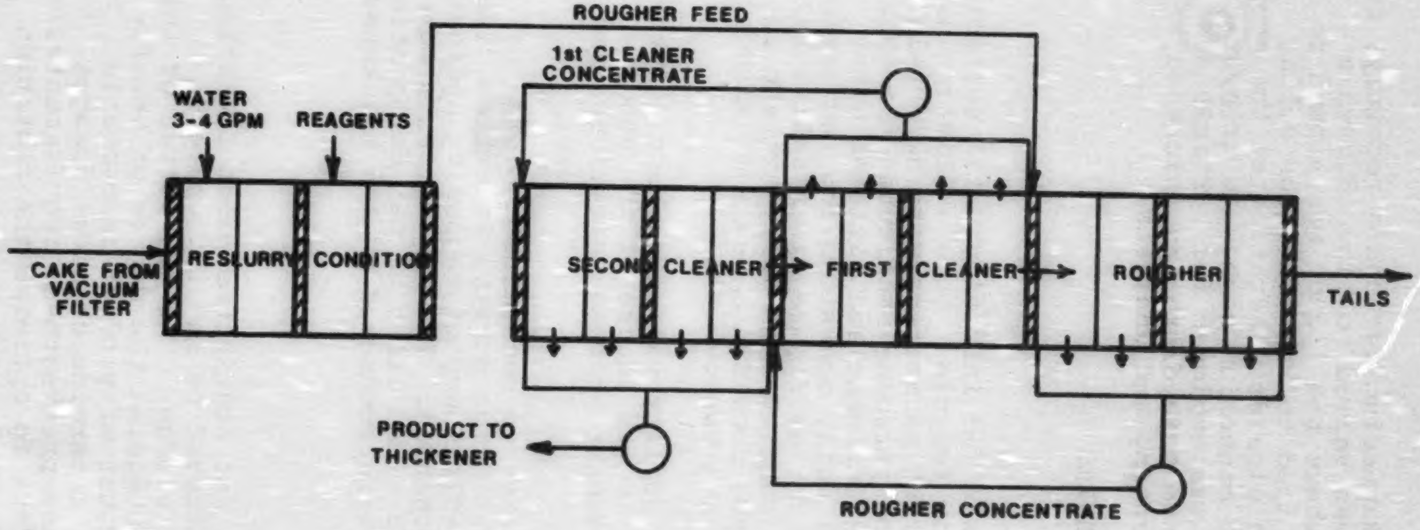
ROUGHER FEED
1st CLEANER CONCENTRATE
WATER 3-4 GPM
REAGENTS
CAKE FROM VACUUM FILTER
RESLURRY
CONDITION
SECOND CLEANER
FIRST CLEANER
ROUGHER
TAILS
PRODUCT TO THICKENER
ROUGHER CONCENTRATE

FIGURE 3. PILOT FLOTATION FLOW DIAGRAM.

Magnesium Recovery

During studies of magnesium carbonate recovery, the magnesium bicarbonate liquor was valved to flow through a hot water heat exchange unit where the liquor was warmed to 30-45°C. The heated liquor, piped to the flotation cells, was air stripped of the carbon dioxide. Aeration at the proper temperature range precipitated magnesium carbonate trihydrate. Recycle of the treated liquor was employed for particle seeding. Precipitated magnesium carbonate trihydrate was thickened and vacuum filtered for further testing and analyses.

DESCRIPTION OF PILOT PLANT STUDIES

Water Treatment Phase

Magnesium sulfate was fed initially until sufficient sludge had accumulated to allow recycle. Once sufficient sludge inventory was achieved, treatment parameters were held relatively constant. Water district plant personnel monitored the treatment process, along with basin influent and effluent water quality parameters. A typical daily operating log indicating the parameters monitored is given as Figure 4. A solids balance around treatment units was calculated from daily average operating data. This solids balance provided a means of sludge inventory and flow control to the various units.

Seasonal raw water quality variations and temperature fluctuations were encountered in the course of the study. Generally, no other water treatment process variations were attempted.

Studies were conducted to determine the effects of sludge temperature, carbon dioxide purity, retention time, and final pH on the rate and efficiency of magnesium hydroxide solubilization in sludge carbonation. Thickening tests were performed on basin sludge before and after normal carbonation, and vacuum filter leaf tests were conducted on the thickened sludge.

Flotation Studies

Open circuit bench and continuous pilot flotation studies were periodically conducted on the carbonated, thickened and vacuum filtered sludge. The objectives of the flotation studies were to: determine the degree of beneficiation achievable and the amount of product recoverable using the flotation process; determine chemical dosages, process control parameters, and pretreatment requirements, if any; and develop design data to optimize the flotation process.

Date	Softening Basin															Sludge							
	Basin Influent					Chemicals Applied				Rapid Mix pH	Basin Effluent					Carbonator Influent		Chemicals Applied		Carbonator Effluent		Thickener Underflow	
Time	Flow MGD	Total Alk. mg/l	Ca^a as $CaCO_3$	Mg^b as $CaCO_3$	Turb. FTU	Lime mg/l	847A mg/l	Mg(HCO$_3$)$_2$ Level	Mg(HCO$_3$)$_2$ gph		pH	CaH mg/l $CaCO_3$	MgH mg/l $CaCO_3$	Total Turb. FTU	Acid Turb. FTU	pH	Dry wt. Solids	CO_2 cfm	Air cfm	pH	Total Alk (mg/l)	gpm	% Dry Wt. Solids
0100	2.0					170	0.21	4'7"	9	11.6								12	0	7.1			
0200	2.0					170	0.21	4'9"	9	11.4	11.4	140	12	7.4				12	0	7.1			
0300	2.0					170	0.21	5'2"	10	11.4								12	0	6.9			
0400	2.0					170	0.21	4'6"	10	11.4	11.3	140	4	6.6	0.8			12	0	7.1			
0500	2.0					170	0.21	4'1"	10	11.4								12	0	6.9			
0600	2.0					170	0.21	3'8"	10	11.4	11.3	128	16	7.5	1.3			12	0	7.0			
0700	2.0	132	148	44	170	170	0.21	4'0"	8	10.5								12	0	6.9			
0800	2.0					170	0.21	4'2"	9	11.3	11.3	130	26	7.5	1.7			12	0	6.9	9000		8.6
0900	2.0					170	0.21	4'2"	9	11.3								12	0	6.9			
1000	2.0					170	0.21	4'2"	9	11.5	11.3	116	24	6.4	1.6			12	0	7.0			
1100	2.0					170	0.21	4'3"	9	11.4								12	0	6.9			
1200	2.0					170	0.21	4'4"	9	10.5	11.3	118	24	7.6	1.5			12	0	6.9	11000		
1300	2.0					170	0.21	4'4"	9	11.3								10	0	6.8			
1400	2.0					170	0.21	4'4"	9	11.3	11.2	112	28	6.2	1.4			10	0	7.2			
1500	2.0	170	170	40	45	170	0.21	4'4"	9	11.1								10	0	7.2			
1600	2.0					170	0.21	4'4"	9	11.3	11.2	102	28	6.3	1.3			10	0	7.3	8400		
1700	2.0					170	0.21	4'4"	9	11.2								10	0	7.2			
1800	2.0					185	0.21	4'5"	9	11.2	11.2	96	32	4.7	1.2			10	0	7.5			
1900	2.0					185	0.21	4'5"	9	11.0								10	0	7.3			
2000	2.0					185	0	4'6"	10	11.3	11.2	116	12	4.5	2.8		5.0%	10	0	7.3	9600	2.9	10.6
2100	2.0					185	0.21	4'4"	10	11.3								10	0	7.3			
2200	2.0					185	0.21	4'0"	10	11.5	11.2	118	34	6.2	1.8			10	0	7.5			
2300	2.0	184	202	38	45	185	0.21	3'8"	10	11.1								10	0	7.4			
2400	2.0					185	0.21	3'6"	10	11.3	11.1	120	26	7.5	1.7			10	0	7.4	7600		
AVERAGE		162	173	41	87	174	0.20		9.3	11.2	11.2	120	22	6.5	1.4		5.0%	11	0	7.2	9080	2.9	9.6

a - Calcium Hardness

b - Magnesium Hardness

Figure 4. Daily Operating Record

In the normal operation of the Permutit unit, a relatively long sludge retention time (approximately 20 days) was maintained in the settling basin and thickener. This storage capacity provides a sludge of relatively constant character over short study periods. A wide range in sludge calcium carbonate purity was encountered, resulting from fluctuation in raw water turbidity. Ranges in particle size distributions, residual magnesium contents, water temperatures, and levels of impurities and interferences were also experienced in the course of the project.

Process control variations studied included collector type and dosage, pH, pulp density, pulp temperature, number of cleaning stages, residence time in stages, modifying and dispersing agents and dosages, and artificial as well as background impurities and interferences.

In order to further evaluate product purity, 5-10 gram samples of the flotation product were dewatered, dried, and ignited at 1900 °F for four hours using a laboratory muffle furnace. Pure analytical grade calcium carbonate was also calcined under the same conditions for comparison.

Magnesium Recovery

Magnesium was recovered as magnesium carbonate trihydrate on several occasions during the study period. The recovered product was analyzed for type and amount of impurities.

PROJECT LIMITATIONS

While the existing Permutit precipitator saved considerable construction expense and time, several problems resulted from its use. The unit was designed to treat a total of 20-MGD, 10 million in each side. The flow metering and control device was, therefore, sized to handle a much higher rate than the normal 2-MGD treated during the study. The flow control, at 2-MGD, varied depending on the head available from the presedimentation tanks. This problem was partially solved by increasing the water treatment flow to 4-5-MGD. In that range, more accurate metering and control was found.

As discussed previously, the sludge withdrawal system did not provide positive solids removal from the basin. As the water and solids balance is extremely important from an experimental standpoint, the desludging system proved to be a major deficiency. Accurate inventory of solids was impossible to maintain. Also, sludge wasting during backwashing of the collection system occurred frequently. These problems would not be associated with a normal clarification system.

The deficiencies in the sludge withdrawal system caused low solids in the sludge underflow such that the average recycle alkalinity was only 6,000 mg/l. In previous studies with a positive sludge collection system, carbonated alkalinities of 15-16,000 mg/l could be easily obtained. Figure 5 represents a relationship between carbonator feed sludge solids and magnesium level obtained after carbonation assuming 13.8% $Mg(OH)_2$ in the sludge.

As discussed previously, no attempt was made to monitor the process after clarification. It would have been desirable to include two-stage stabilization and filtration for comparative purposes. Previous projects have shown, however, that successful stabilization and filtration are readily achievable assuming that the water has been properly treated in prior units. Present single-stage stabilization caused the effluent from the demonstration plant to have a much higher hardness than effluent from the conventional process. This added hardness results from the dissolved calcium, at the elevated pH, not precipitating during carbonation. The inability to properly stabilize the pilot plant settled water caused a slight increase in the water hardness from the plant. Laboratory stabilization studies were used to evaluate water quality following two-stage stabilization.

The turbidity in the pre-settled water was much lower than had been experienced in previous years. As discussed, the lower turbidity resulted from more careful coagulant control in the presedimentation process. Blending of well and river water was not found to be necessary to control water quality. In fact, the suspended solids were below desired levels during most of the study.

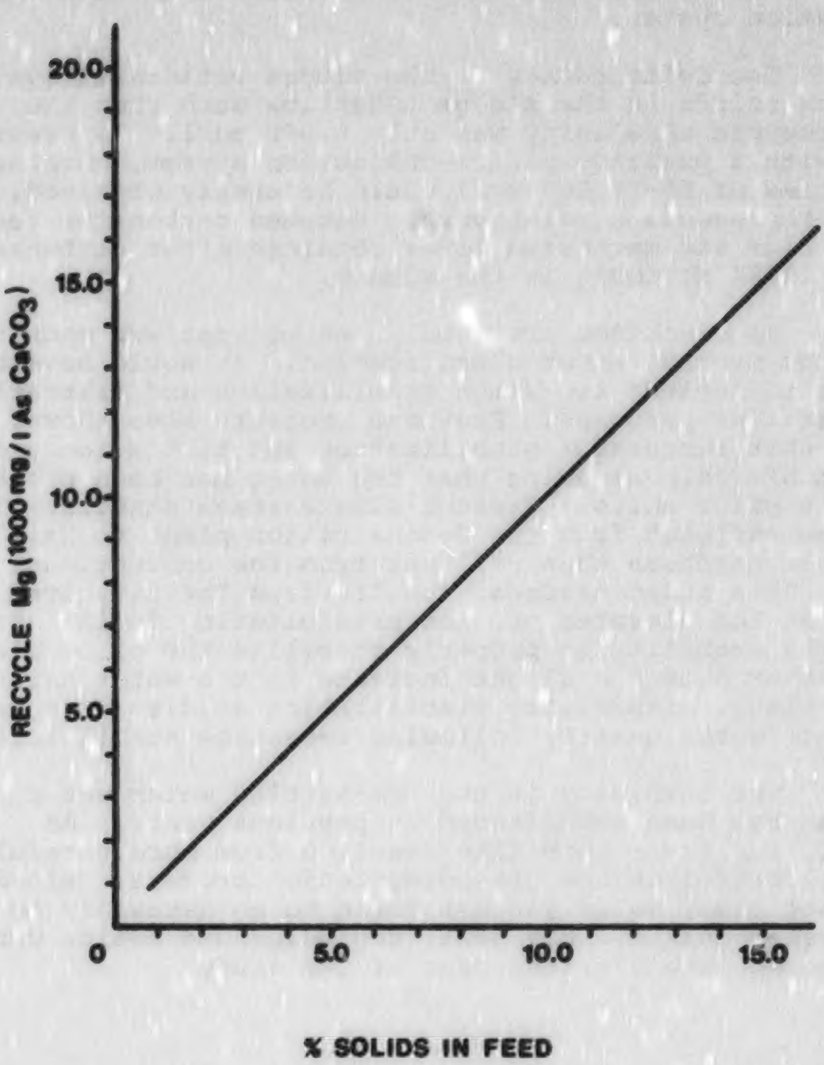

FIGURE 5. CARBONATOR FEED SOLIDS vs. MAGNESIUM IN THE RESULTING RECYCLE.

SECTION V

RESULTS AND DISCUSSION

Operation of the water treatment units began the week of January 2, 1975. Carbonation of basin sludge began the following week. Flotation studies did not begin until the month of February.

Weekly summaries of the operating records are included as item A in the appendix. The inability to accurately measure and control raw water flow caused erroneous data reporting in the early study phases. Increased flow, beginning in August, allowed more accurate flow measurement and subsequent chemical dosage calculations. The chemical feed data reported in Appendix A was unavoidably subjected to considerable error and can only be used cautiously. Poor correlation between soluble magnesium determination using EDTA titration and atomic absorption methods was found. Titration technique and testing procedures were carefully checked and found to be satisfactory. Residual magnesium levels reported in the appendix often contradict previous study findings (8,9). Analytical interferences are suspected; thus caution is advised when attempting to correlate residual magnesium with coagulation pH. Of the more than 30 raw waters studied to date, the Kansas River water presented the only problem achieving a reasonable magnesium determination using EDTA. Additional studies using the various inhibitors available could result in more accurate EDTA titration for residual magnesium.

Figure 6 summarizes the water treatment data on a monthly basis. Excellent turbidity removal was obtained throughout the study period. As practiced in previous studies, acid turbidities were used to measure true residual turbidity not removed in coagulation and clarification. Conventional turbidity analysis was also performed and reported. The difference between the two turbidity values is caused primarily by suspended calcium carbonate, which is readily removed by filtration and does not significantly shorten the length of the filter cycle. Acid turbidity is highly correlated with the filtered water turbidity; thus, is an excellent indicator of coagulation-sedimentation efficiency.

Inventory of solids in the various operating units was maintained by mass balance calculations. These balances proved to be of assistance primarily from an operational standpoint. The solids balance summary sheets are shown as Item B

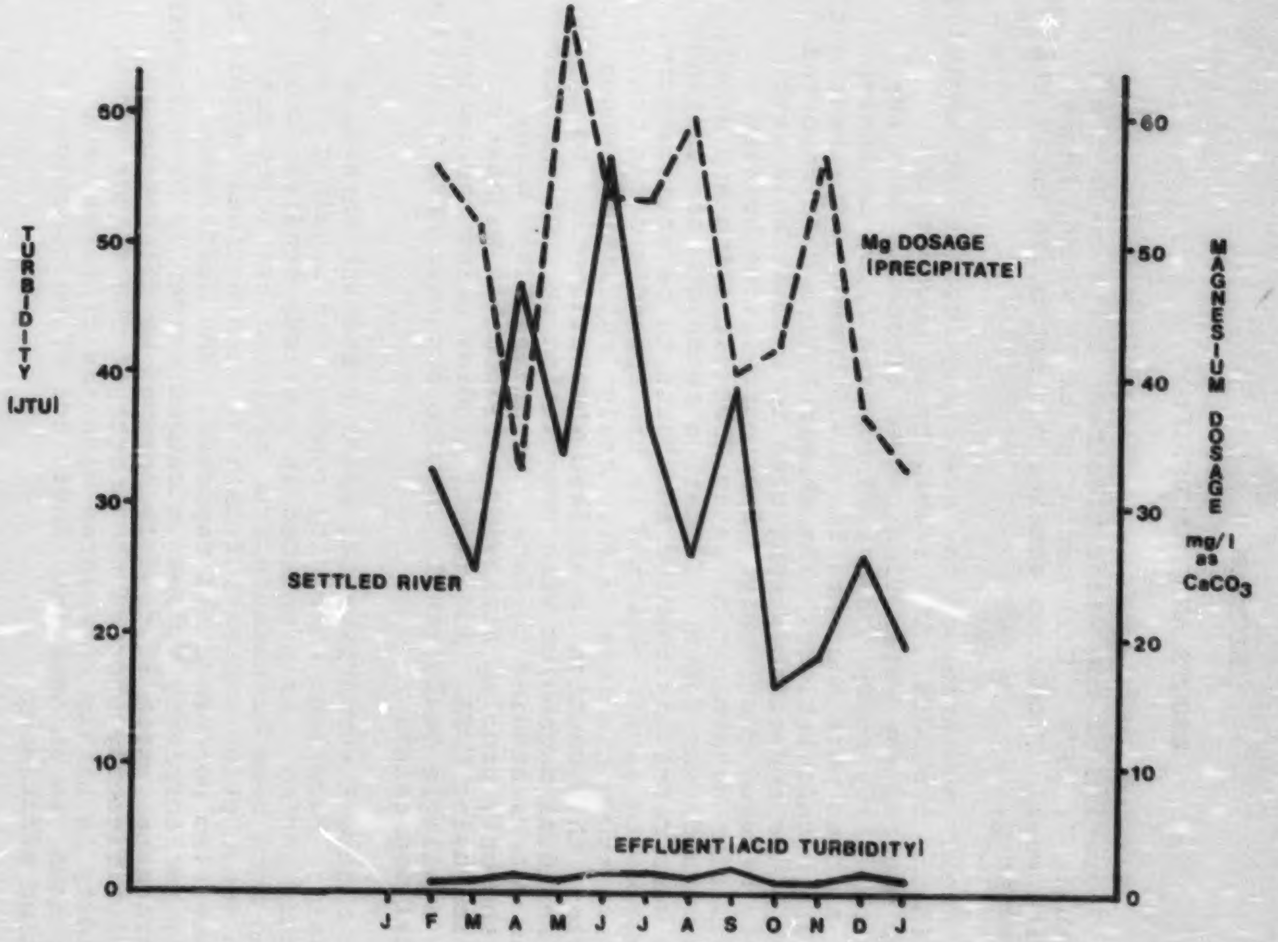

FIGURE 6. MONTHLY AVERAGE TURBIDITY AND MAGNESIUM DOSAGE.

in the appendix. The balances shown were calculated from raw water quality and recycle data. The contributors to production of calcium carbonate, suspended solids, and magnesium hydroxide were identified. The turbidity to suspended solids ratio was found to be approximately 1.

The literature documents the effectiveness of magnesium hydroxide for removing dissolved silica. Silica removal is important, particularly for industrial boiler and cooling tower uses. A study was conducted between October and January to evaluate the effectiveness of the recycled magnesium on silica removal. Silica was measured on the settled river water, Permutit basin effluent, and on three occasions on conventional treatment effluent. Table 4 compares silica levels in the settled river and effluent from the Permutit basin. Silica removal averaged 72% over the two-month study period. The conventional treatment provided an average of 28% removal of silica.

Silica concentrations in the recycle liquor increased to 1,650 mg/l before an equilibrium was reached. Silica removal efficiency in water treatment was apparently not reduced as a result of the high level of silica in the recycled magnesium bicarbonate liquor.

Although silica removal with magnesium hydroxide has been used successfully many times, the ability to recover the magnesium, recycle the coagulant for hundreds of cycles, and effectively remove raw water silica is an important finding.

Considerable expense is required for silica removal for industrial users, thus simultaneous removal of silica with water treatment may be of major interest.

The excessive magnesium loss in the thickener blowdown required initial make-up feed of magnesium sulfate. This magnesium source, expressed as calcium carbonate, costs in excess of $.30/lb of magnesium. Figure 7 illustrates the effect of thickener underflow solids, which are controlled by pumping rate, and magnesium loss. Based on the assumptions shown, an additional make-up cost of $60/day would be required if 15% solids were pumped, as opposed to 40%. During the study period an average of 25 mg/l of magnesium as calcium carbonate was precipitated from the raw water; thus, a magnesium loss of 416 lb/day could be accepted without need for make-up. Make-up magnesium was not required when thickener underflow pumping rates were carefully controlled.

TABLE 4. SILICA REMOVAL USING RECYCLED MAGNESIUM

	Silica (mg/l Silicon)		
Date	Settled River	Permutit Effluent	% Removal
10-5-75	30.7	6.7	78
10-12-75	16.7	8.4	50
10-19-75	24.7	12.8	48
11-9-75	47.8	11.7	76
11-16-75	43.7	21.7	50
11-30-75	76.0	12.0	84
12-14-75	78.0	38.0	51

Note: All samples are 24 hr composited. Samples were treated with acid prior to Silicon determination by atomic absorption analysis.

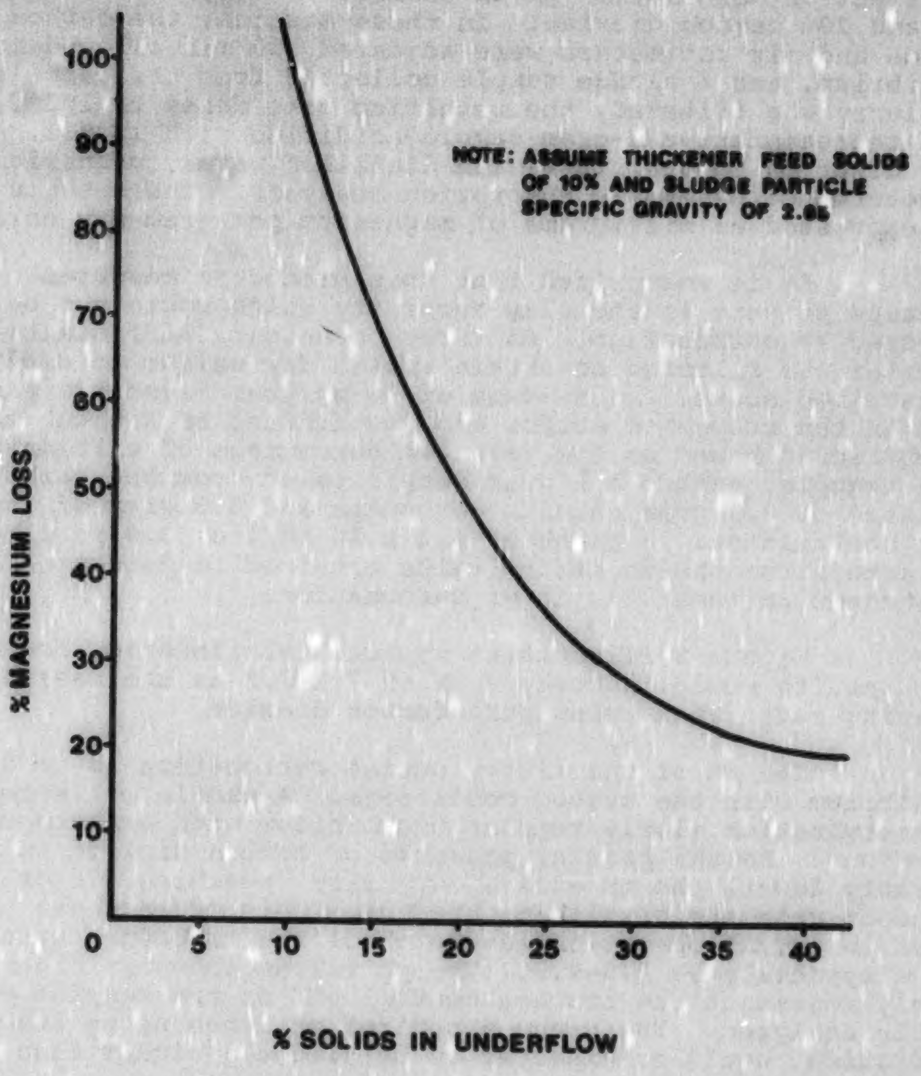

FIGURE 7. EFFECT OF SLUDGE SOLIDS IN UNDERFLOW ON MAGNESIUM LOSS.

Carbonation Studies

A series of experiments were conducted to determine the effect of carbonation pH on undissolved magnesium using pure and 20% carbon dioxide. In these studies, the carbon dioxide and air rotameters were adjusted, 30 min allowed to reach equilibrium, and a sludge sample collected from the carbonator. The slurry was filtered, the resulting cake dried to 103°C, and a representative 1-gram sample acidified with 1N HCl. After dilution to one liter with distilled water, magnesium was determined by atomic absorption analysis. The results were expressed as milligrams of magnesium per gram dry cake.

It is recognized that this procedure measured magnesium present in the clay turbidity which would not be recovered by carbonation. On three occasions, sufficient raw water was filtered to obtain enough dry solids to analyze as described above. An average of 10 mg/gram magnesium was found in the suspended solids and was treated as a blank to be subtracted based on the relative percentage of silt present. As an example, assume a 1 gram sample taken from the carbonator consisted of 0.7 gram calcium carbonate and 0.3 gram of raw water contaminant. A blank of 0.3 x 10 mg/l or 3.0 must be subtracted from the magnesium value obtained to determine the true magnesium remaining after carbonation.

Figure 8 illustrates typical relationships found. These results would indicate a pH of 7.1-7.2 as the desirable operating range when using pure carbon dioxide.

The pH of the slurry during carbonation is in dynamic equilibrium with the system conditions. A sample collected for pH determination slowly reaches equilibrium with atmospheric conditions. As the partial pressure of carbon dioxide is considerably lower, the pH will slowly rise, reaching 8.0 or higher, dependent upon the alkalinity present. This pH increase is experienced in actual operation as the pH of the thickener underflow sludge typically is 7.5-8.0. The pH values shown in Figure 8 closely represent the process control pH, as the samples were quickly analyzed. The process control pH, when using 20% carbon dioxide, would be expected to be slightly higher than for pure carbon dioxide.

Carbonating more concentrated sludges to produce magnesium levels near equilibrium, could result in precipitation and loss of soluble magnesium as a result of the pH increase. A covered thickener, using a carbon dioxide blanket, would prevent the carbonated slurry from contact with the atmosphere. Capital costs are added and may not provide advantages

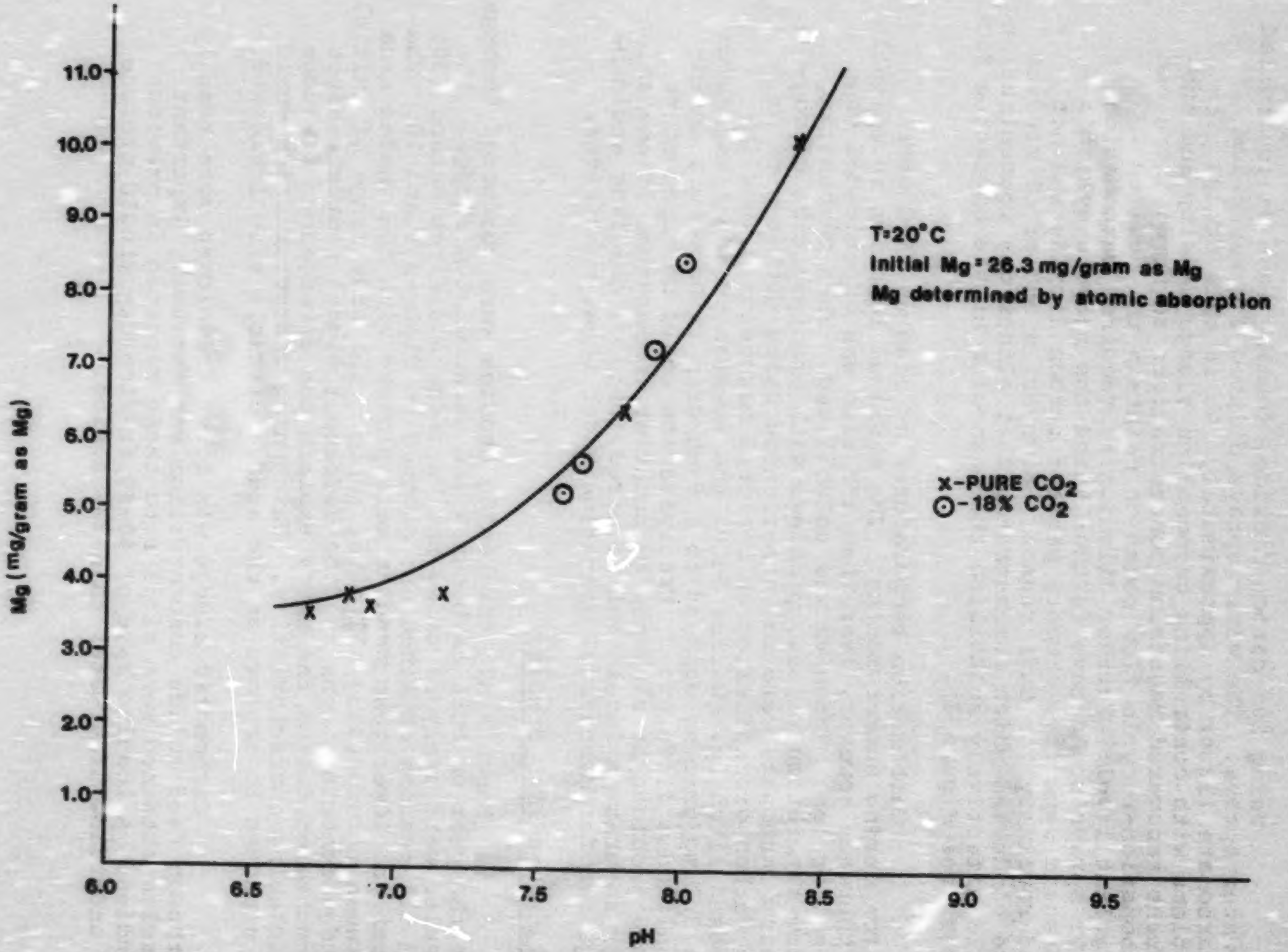

FIGURE 8. MAGNESIUM REMAINING IN SLUDGE CAKE AT INDICATED CARBONATION pH. JOHNSON COUNTY, KANSAS

when carbonation is below saturation levels. Problems with reprecipitation during thickening were not experienced with magnesium levels of 8,000-10,000 mg/l as calcium carbonate.

Using 20% carbon dioxide, foaming must be controlled by water sprays. The water sprays diluted the magnesium bicarbonate liquor by approximately 10% in this study. The problems with controlling carbonation sludge density and subsequent recovered magnesium concentrations required increased carbonation-recycle flow rates to maintain the desired coagulant level. Further dilution by required carbonation water sprays would have further taxed the recycle system's hydraulic capacity. Twenty percent carbon dioxide was not used routinely for this reason. However, a number of studies were conducted which demonstrated that either gas concentration would effectively solubilize the magnesium at the operating flow rates (see Figure 8).

Carbonation temperatures as high as 28°C were common during summer months. The chemical reaction is slightly exothermic; however, less than 1°C rise was experienced when 10 g/l or less magnesium was solubilized. When carbonating below saturation values, problems with precipitation of magnesium carbonate were not experienced using either pure or 20% carbon dioxide although residual magnesium values increased slightly. During July, the average residual magnesium was 3.2 mg/gram as opposed to 1.6 mg/gram in December, an insignificant difference. Precipitation could be expected to cause problems at elevated carbonation temperature if operation near saturation levels was required. Sludge chilling would be required for successful operation under these conditions.

Solids Handling Studies

Bench scale thickening studies were conducted throughout the year on both carbonated and uncarbonated sludge. The results were analyzed using the Talmadge and Fitch method (30) and all results obtained are plotted in Figures 9 and 10. The upper and lower test results were plotted with the shaded area between encompassing all other tests. The wide range of initial sludge concentrations and the different sludge particle sizes encountered during the study explain the divergence of sludge thickening characteristics. Thickening characteristics would be expected to improve as the sludge particle size increased.

Carbonated sludge was found to thicken more readily although feed solids concentration was extremely important. Results obtained were similar to those reported in previous studies. A loading rate of 40-50 ft^2/ton/day should produce an underflow of greater than 30% solids.

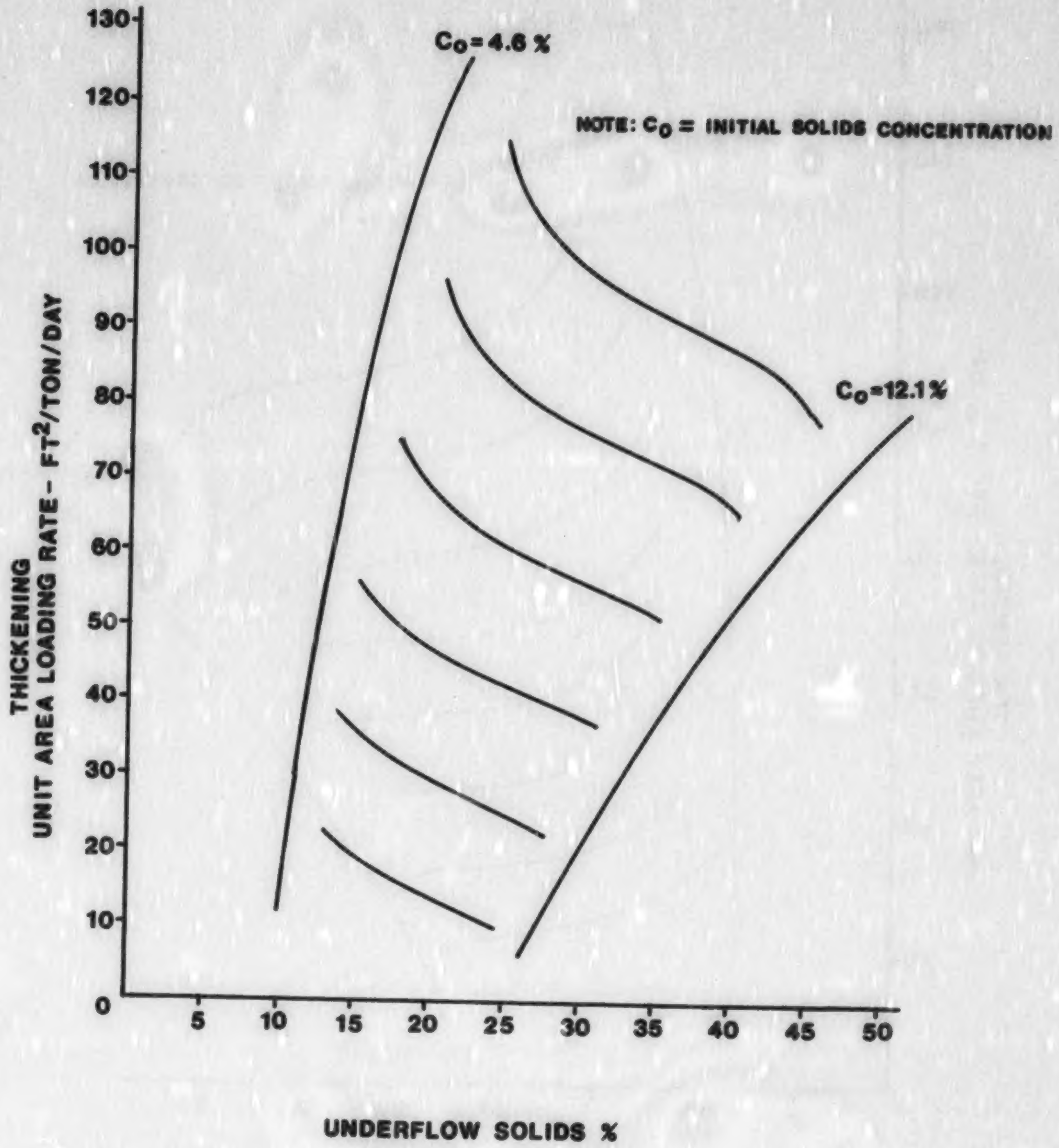

FIGURE 9. SUMMARY OF THICKENING CHARACTERISTICS OF CARBONATED SLUDGE.

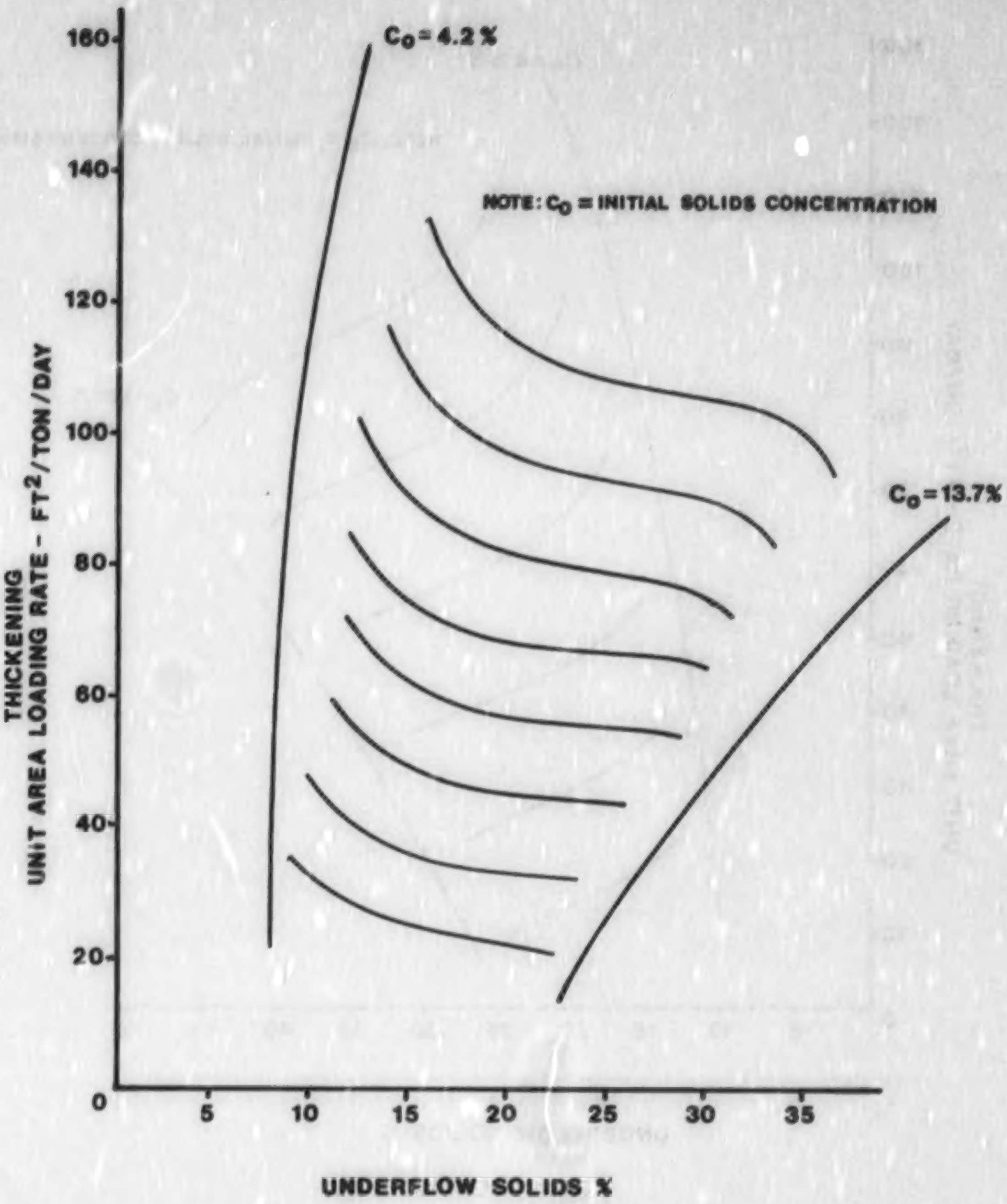

FIGURE 10. SUMMARY OF THICKENING CHARACTERISTICS OF UNCARBONATED SLUDGE.

Vacuum filtration studies were conducted on both a batch and continuous scale. Leaf filter batch tests were found to closely correlate with results obtained with the pilot vacuum filter. Filter rates ranged from 10-25 lb/ft^2/hr. Filtration rates increased with an increase in calcium carbonate particle size and grade.

FLOTATION STUDIES

Initial flotation work began the week of February 10, 1975. Typically, one week out of each month was directed to onsite flotation work. During the study period, 18 sludge samples were collected for flotation evaluation. A summary of all flotation results is shown as Item C in the appendix.

Pilot vs. Bench Scale

Bench scale flotation is used to evaluate flotation parameters on a batch basis just as jar tests are used to evaluate water treatment processes. Generally, several hundred grams of dewatered sludge are floated in a 3-liter cell. All process variations can be studied, requiring only a fraction of the time and materials that a similar pilot scale study would require. Impellor speed, air flow rates, and pulp temperature are readily controlled. Typically, 10-15 sets of operating conditions could be studied each day.

Pilot scale testing generally required 3-4 hours for each series of process conditions. Typically, 100-150 lb/hr dry solids were dewatered and reslurried for flotation. Considerable effort was necessary to 'balance' the process. Samples were collected every 30 minutes and composited over the duration of the run. Generally, only two sets of flotation operating conditions could be studied each day.

Obvious advantages of the bench scale studies encouraged greater use. It was important initially to demonstrate that the bench scale accurately reflected results obtained in the pilot scale. When treating similar sludges under the same process conditions, the concentrate grades and recoveries were found to be very nearly the same. This proved as expected based on experiences* reported in the mining industry.

Table 5 summarizes flotation data collected during the months of February and March. Comparing pilot versus bench scale results, note the close agreement between the final grade obtained in the number 2 cleaner, which is the product. This comparison can be made for all pilot and bench scale data, summarized as Item C in the appendix.

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* Communication with the Galigher Company

TABLE 5. SUMMARY OF FLOTATION RESULTS
February and March
Bench Scale

Sample #	Feed		Chemicals #1 Ton			% $CaCO_3$ - by Acid Base				
	% Solids	pH	Silicate	Soda Ash	Dresinate	Feed	Tails	RoCon	#1Cl.	#2Cl.
2/10-2	--	9.1	3	2	2.6	89.7	61.3			96
2/10-4	--	--	2	3	2	89.7	62.9			97
2/24-1	10	9.0	1	1	1	86.3			89.6	
2/25-1	10	--	2	1	2[a]	86.3	69.0			92.2
2/25-2	10	--	2	1	2	86.3				97.8
2/27-2	10	9.3	2	0	2	75.0	60.0			88.8
3/17-1	10	9.6	2	1	4	91.8	83.3	95.1	95.7	98.3
Pilot Scale										
2/11/75	5.4	8.7	0.67	1.25	1.53	87.1	82	--	93	95
2/13/75	--	8.95	5		8	87.2	85.1	90.8	92.3	95.1
2/14/75	5	----	4.8		11[b]	94.8	68.3	94.8	98.5	--
2/25/75	5.73	----	6.7	3.3	7.04	87.3	80.8	89.3	90.8	98.8
3/19/75	7.8	8.90	5.5	2.7	5.5	89.7	87.5	90.2	93.0	98.3

[a] - Mixture of Dresinate and Sodium Alkyl Sulfate (1:1)

[b] - Emulsion of 1% Dresinate and 0.05% Sodium Alkyl Sulfate

While the data for the chemical feed and grade of the tails shown in Table 5 do not compare favorably, the cause of this difference will be discussed in following sections.

Product grade was found to be the determining factor for successful flotation. Recovery and chemical efficiency were secondary considerations as improvement could be made by process optimization. All data collected support the conclusion that successful bench scale results indicate success for the pilot flotation studies.

The pilot scale studies were necessary in order to produce sufficient material to study thickening, clarification, and filtering of the concentrates and tails. In the latter project stages, this was the primary function of pilot scale studies.

Effect of Calcium Carbonate Particle Size on Flotation

Early flotation study results indicated little difficulty in producing high concentrate grades with modest recovery. The studies conducted in February and March generally found concentrate grades of 97-98% possible as shown in Table 5. Recovery was usually found to be less than 70%; however, initial concern was producing an acceptable grade.

In April studies, the results indicated that there was no collector selectivity. The concentrates often were lower in calcium carbonate than in the tails. The froth physical character had drastically changed. Initial efforts were directed to various chemical feed combinations. Review of the data indicated that the level of residual magnesium had increased from approximately 3.0 mg/l to approximately 6.0 mg/l. Efforts were then directed to reduce the residual magnesium by a number of means. The filter cake was washed, the carbonation was more carefully controlled, the carbonation temperature was artificially reduced, the slurry was washed and repulped, the magnesium level was reduced using ion exchange resin, plus other treatments. All efforts found only marginal success in lowering residual magnesium and offered no improvement in flotation results.

Beginning in June, the particle size of the sludge was determined using a Coulter Counter* along with microscopic examination. There are a number of descriptive denominators for particle size; however, D_{10}, which is the size exceeded by 90% of the particles, appears to be unusually important. Other descriptors include D_{65}, D_{60}, and D_{90} which are defined in a similar manner. The uniformity coefficient Cu (D_{60}/D_{10}) describes how uniform the particles are in size. Results of all particle size analyses are shown in Table 6 along with feed and product grades found in flotation studies.

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*a product of Coulter Electronics Co., Inc., Hialeah, FL

TABLE 6. PARTICLE SIZE ANALYSIS SUMMARY
JOHNSON COUNTY, KANSAS

Sample	Particle size in Microns (u)					Uniformity Coefficient
	Max.	Min.	D_{65}	D_{60}	D_{10}	
Carbonated Sludge (6/9)	20	0.8	5.6	5	1.5	3.33
Carbonated Sludge (6/12)	16	0.8	4.2	3.7	1.2	3.22
Carbonated Sludge (8/28)	25	0.8	6.1	5.4	1.8	3.0
Lagoon Sludge[a]	40	1.5	15.5	14.4	4.4	3.27
Accellator Sludge[a] (8/28)	40	2.5	18.0	16.8	5.3	3.17
Accellator Sludge[a] (10/30)	65	2.9	18.2	17.0	6.7	2.54
Carbonated Sludge[a] (10/30)	25	1.6	8.2	7.8	3.8	2.08
Carbonated Sludge[a] (11/17)	33	1.0	16.2	15.3	5.6	2.73
Carbonated Sludge[a] (12/15)	33	1.0	14.5	13.8	4.9	2.85

[a]- Sludge recirculation practiced

A sample of lagoon sludge, primarily resulting from conventional treatment, was collected for bench scale studies. Following carbonation to remove residual magnesium, excellent selectivity and recovery were found. A product grade of 97% with recovery as high as 91% was found. It was noted that the particle size distribution was considerably larger than previous sludges that were not successfully floated. The magnesium residual after carbonation was 7.9 mg/gram, thus, refuting the argument that high residual magnesium caused flotation interference.

It was reasoned that an aging process had resulted in the crystal growth and possibly altered the form of the residual magnesium, eliminating the interfering action.

A sample of sludge directly from the Accelator was collected on 8/28. This sludge was carbonated and dewatered prior to bench scale flotation study. Results indicated that the calcium carbonate was readily floatable. Again, particle size data indicated this sludge to be substantially larger than the carbonated sludge produced in the pilot plant.

Early in September, the rapid mixer motor on the Permutit system failed. Inspection found the mixer to be heavily coated with calcium carbonate indicating that sludge recycle had not been practiced. Inspection of the recycle pump found it out of service. Sludge recycle has been used to prevent encrustation on mixing equipment and as discussed in Section 1, particle size is significantly influenced by sludge recycle.

The recycle pump was repaired, the basin cleaned, and the system allowed to reach equilibrium. Sludge samples collected had a D_{10} of 3.8 μ, considerably higher than previous samples having a D_{10} of 1.5 μ. In flotation studies, once again, collector selectivity was found and the calcium carbonate was easily separated from the sludge.

A brief study was made to distinguish between calcium carbonate and raw water contaminant in the size analysis. A sample of sludge collected on June 12 was separated into two representative samples. One sample was treated with acid to dissolve all of the calcium carbonate present. This sample was then neutralized with sodium hydroxide to pH 7.0. Both samples were analyzed for particle size distribution with the results shown in Figure 11. These results indicate that, in the upper size range, the raw water contaminants contribute only to a minor extent. For comparative purposes, particle size analysis for a sample collected after sludge recirculation was reinstated (10/30) is included.

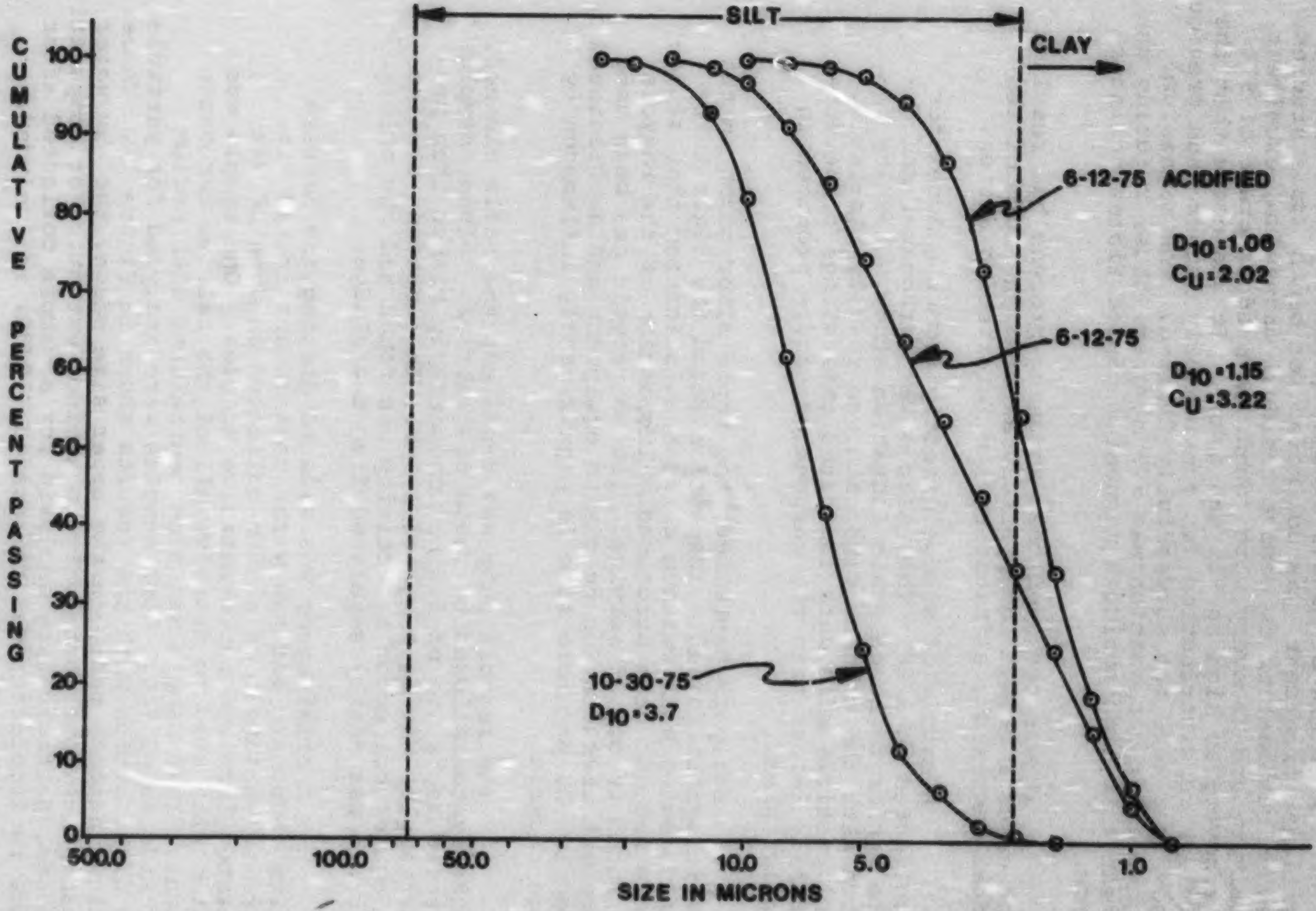

FIGURE 11. PARTICLE SIZE ANALYSIS COMPARISON

Effect of Collectors, Modifiers, and Pulp pH

Chemical feed variations were studied in all flotation experiments; however, the work with the sludge collected on December 15 was the most extensive.

Three types of Dresinate* collector were studied: 81, TX-60W, and DS-60W. A general comparison of properties and costs is included in Table 7. Figure 12 illustrates the product recovery effectiveness of the collectors at various feed rates at the conditions stated. It was found that product grade was relatively unaffected by either level or type of collector studied. Economics and performance would dictate that TX-60W be selected as the logical choice of collectors.

The level of collector added greatly affects recovery, but has little effect, if any, on grade. From a practical standpoint, 4-5 lb collector/ton dry solids to be floated is the maximum feed rate which can be handled. Increased collector causes severe foaming in the float. Staged feeding of the collector to the rougher was found helpful.

The adjusted pH of the conditioned pulp was found to drastically affect product recovery, but demonstrated only a minimal effect on grade. As illustrated in Figure 13, an optimum pH range of 9.0-9.5 was found, generally in agreement with the reported literature. As discussed in Section I, this is the pH range of minimum zeta potential for the calcium carbonate as well as the pH necessary to insure that the Dresinate be in the soap form.

The effect of sodium silicate addition to conditioning was somewhat difficult to evaluate. As discussed previously, silica removal was accomplished in the water treatment process. Some of the silica was solubilized on magnesium recovery. The silica level in the recycle stream, however, stabilized, thus not requiring 'blow-down' of recycled magnesium bicarbonate. The silica present in the recycle reached 1,650 mg/l as silica during most of the period of flotation study. Moisture remaining in the filter cake would add approximately 2 lb silica/ton dry solids. It was, therefore, impossible to evaluate the effect of

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* Products of Hercules, Inc., Wilmington, Delaware

TABLE 7. DRESINATE COMPARISON

	Dresinate 81	Dresinate TX-60W	Dresinate DS-60W
Description	87% solids, modified aqueous solution of sodium soaps of dark rosin and pale processed or modified rosins	60% solids, aqueous solution of a fully saponified sodium soap of tall oil	60% solids, aqueous solution of a sodium soap of a specially processed tall oil fraction.
Typical Use	Mainly as an emulsifier ingredient in solvent cleaners	Soap emulsifier in manufacture of road surfacing asphalt anionic emulsions (RS and MS types)	Low cost, anionic flotation reagent
Free Alkali Content, % dry basis NaOH	-	0.5 Max	2.0 Max
Viscosity (Stormer), poises at 60 °C	5.7	5	30
Color	Brown	Dark Brown	Dark Brown
pH of a 25% aqueous solution	-	-	11
Availability	Carload, or drum	Bulk only	All
Cost $/per 100 lb FOB Savannah, Ga.	26.15 (Carload)	10.45 (Bulk)	5.00 (Bulk)

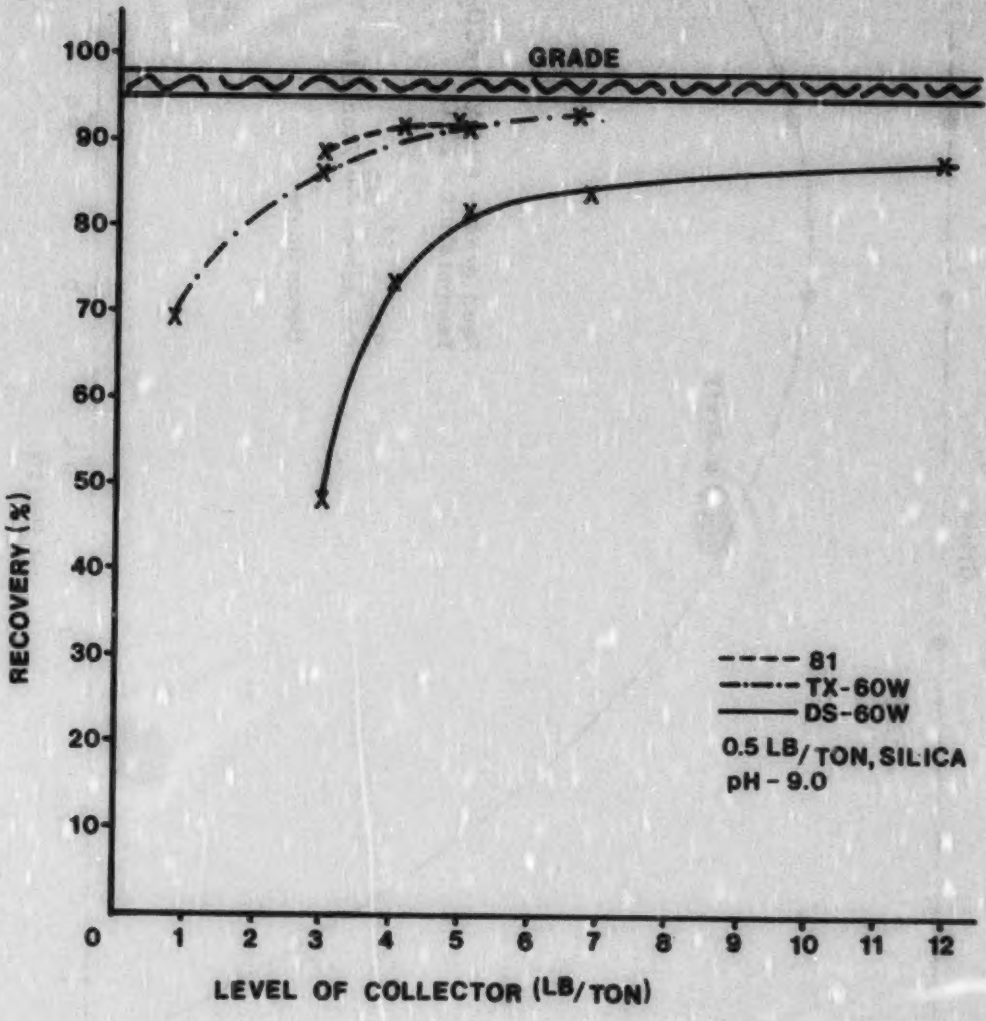


FIGURE 12. COMPARISON OF RECOVERY EFFICIENCY AT INDICATED COLLECTOR LEVEL AND TYPE.

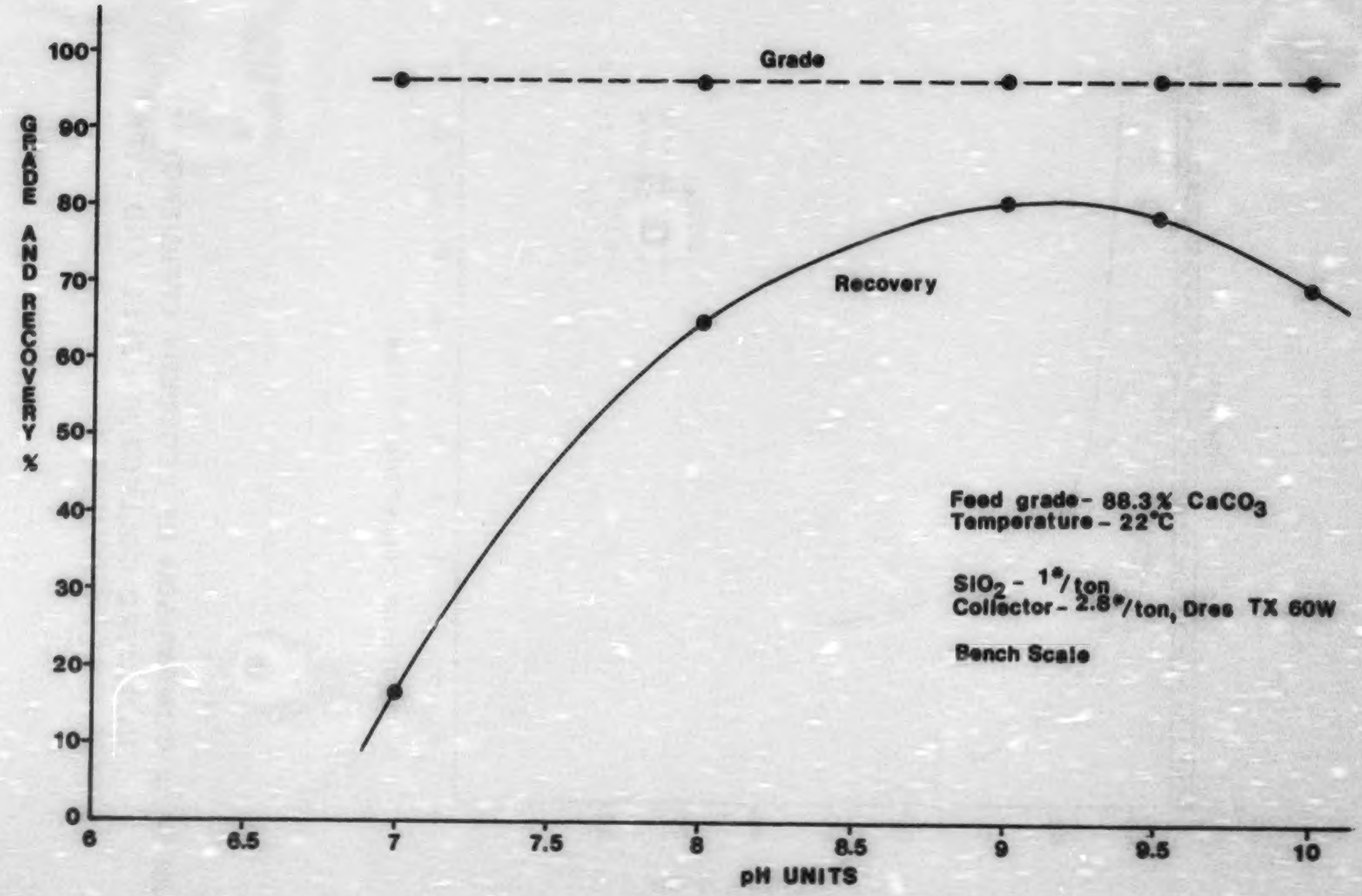


FIGURE 13. EFFECT OF pH ON $CaCO_3$ FLOTATION.

zero silica; however, it is concluded that added silica does not increase, and probably decreases, calcium carbonate collection. Silica is an effective dispersant which can be used to disperse the clay particles. Unfortunately, silica has been shown to also disperse the calcium carbonate; thus, the overall effect is often lower collection efficiency.

A series of bench scale experiments was performed to investigate the effect of added magnesium bicarbonate on the flotation process. The tests were performed on the pilot plant sludge sample collected December 15, 1975, having a feed grade of 85.3%. This sludge contained 3.0 mg/gram of residual magnesium, which is quite low in comparison with the other sludges studied.

A magnesium bicarbonate solution was used to add increasing levels of magnesium to the pulp prior to conditioning. Results of these tests are shown in Table 8.

TABLE 8. EFFECT OF ADDED MAGNESIUM ON FLOTATION

Added Magnesium (mg/gram dry solids)	Total Magnesium (mg/gram dry solids)	Results ($\%CaCO_3$)		
		Concentrate	Tails	Recovery
0	3.0	98.4	36.1	92
3.2	6.2	97.6	57.6	81
8.8	11.8	97.6	63.5	76
14.4	17.4	100.0	67.7	67
19.1	22.1	97.7	76.8	52

Note: Collector dosage - 5 lb/ton TX-60W
Silica - 0.5 lb/ton
pH - 9.0

These data indicate that the added magnesium reacts with the collector, much like soap and water hardness, reducing the collection efficiency. The added magnesium does not interfere with collector selectivity, however. The form of the residual magnesium is obviously important in assessing its effect on the flotation process. Soluble magnesium, as evaluated in this study, would be expected to have the greatest effect on reducing collector efficiency.

Figure 14 illustrates the effect of pulp density on product recovery and grade. Again, results agree with the published data.

Temperature was not found to be effective in increasing flotation performance. Perhaps residual silica effects may have masked the effect of increased temperatures. As discussed in Section I, silica becomes more effective in reducing collection efficiency at elevated temperatures.

The use of carbon dioxide replacing air was found to lower the pulp pH below acceptable levels for flotation; thus, efficiency was reduced. Possibly another collector, effective in the acid form, would have produced more encouraging results.

The sludge samples collected from lagoons and the conventional treatment plant contained activated carbon. An increase in collector requirements could be anticipated, although no definitive data were developed. Johnson County has changed the feed point of carbon so that it is added after softening and coagulation; thus will not be present in future sludge.

Size Requirements of Flotation Circuit

Various design parameters have been used to size flotation circuits, including: hydraulic residence time, solids removal rate (lbs/ft^2/min), solids residence time, and hydraulic overflow rates (gal./ft^2/min.). During the pilot plant operation several water and solids balances were performed around each flotation unit. Countercurrent feed makes the balances and subsequent sizing of the various units difficult. Figure 15 illustrates a typical balance found during the pilot studies. The balance was prepared as follows:

1) Flow measurements were made on the rougher tails, rougher and cleaner feeds, as well as floats from the two cleaners.

2) Measurement of the feed and float from the second cleaner allowed calculation of underflow feed to the first cleaner.

3) A similar procedure was used on the first cleaner to calculate underflow to the rougher.

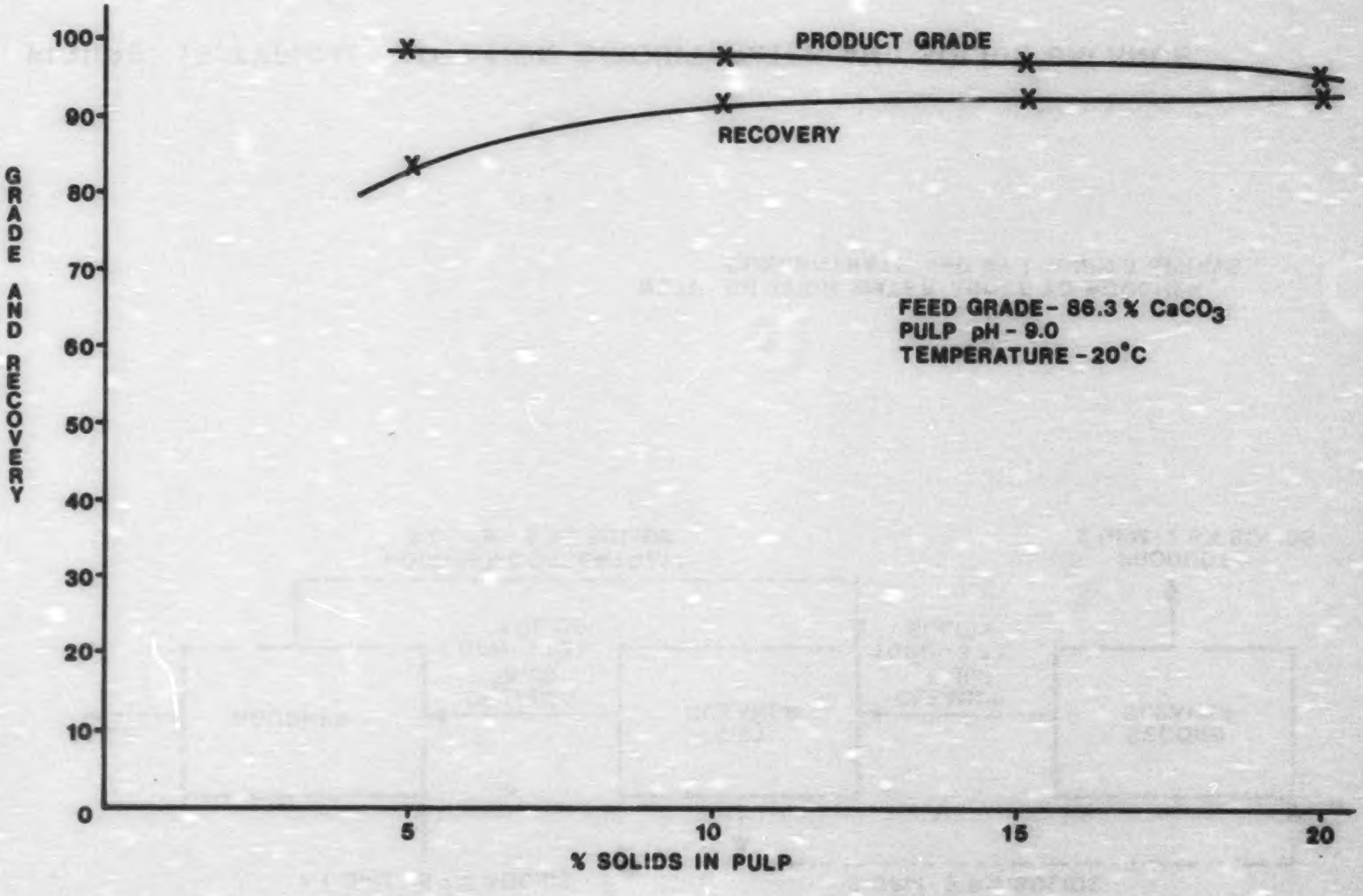
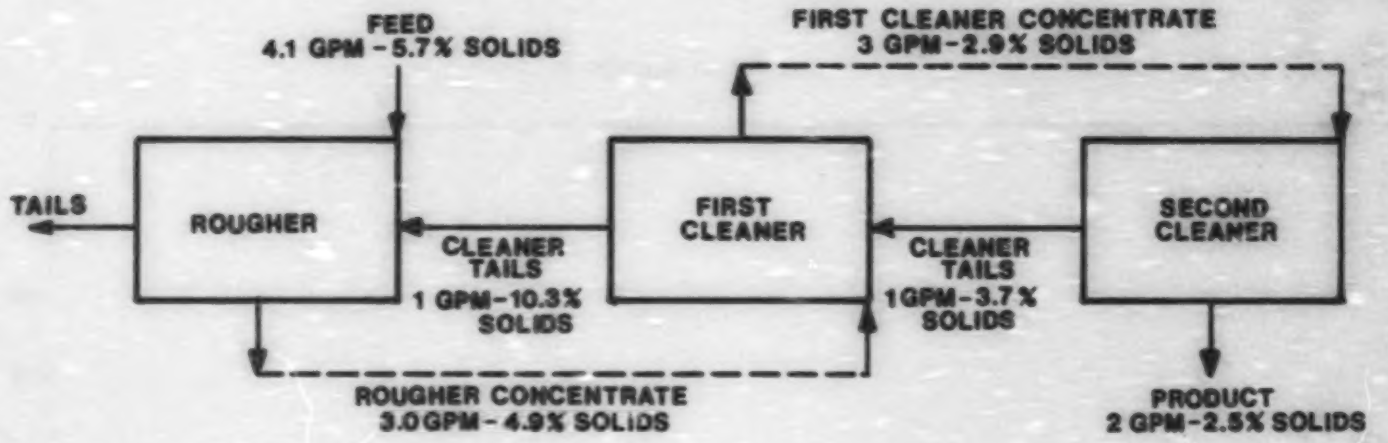


FIGURE 14. EFFECT OF % SOLIDS IN PULP ON FLOTATION PERFORMANCE.


FEED
4.1 GPM - 5.7% SOLIDS
FIRST CLEANER CONCENTRATE
3 GPM-2.9% SOLIDS
TAILS
ROUGHER
FIRST CLEANER
SECOND CLEANER
CLEANER TAILS
1 GPM-10.3% SOLIDS
CLEANER TAILS
1GPM-3.7% SOLIDS
ROUGHER CONCENTRATE
3.0GPM - 4.9% SOLIDS
PRODUCT
2 GPM-2.5% SOLIDS

NOTE: DILUTION WATER ADDED TO ROUGHER CONCENTRATE AND BY LAUNDER SPRAYS.

FIGURE 15. TYPICAL FLOTATION CIRCUIT WATER AND SOLIDS BALANCE.

4) Solids determinations were made on all streams. Solids were identified as either calcium carbonate or 'other'.

Using the above procedure does not produce an exact balance. Overflow losses and solids accumulation in the junction boxes are causes of imbalance. Foaming of the conditioning pulp occasionally causes an overflow to the second cleaner, resulting in contamination of the product. Fortunately, foaming could be avoided by proper operator attention.

Bench and pilot scale study results indicate that hydraulic residence time is the most important design criterion. Pulp density determines solid removal rate for a given residence. Pulp densities above 15% were found to cause excess foaming and solids settling in the launders and junction boxes resulting in overflow from the units. These problems may be a result of the small-scale operation and might not be found in a full-scale application.

The pilot studies found that most of the flotation was accomplished in the first of the two cells for each stage. This was overcome somewhat by stage feeding the collector to the second series of rougher cells. While the change in collector feed was helpful, the froth was only lightly loaded in the second cells indicating that the system was not loaded to capacity. The variation in solids in the float was progressively apparent comparing the rougher with the second cleaner. Each stage had volume of 44 gal. Typical feed flow of 3-5 GPM would result in a hydraulic residence time of approximately 9-15 minutes, not considering underflow to the rougher. Underflow was found to be usually 1 GPM or less. Maximum solids loading with successful flotation was approximately 218 lbs/hr of dry solids for the 2 number 15 Galigher flotation cells used in each stage.

Recovery is established by performance in the rougher cells. Calcium carbonate lost in the rougher tails represents material that will not be recovered; thus design of the rougher circuit is of primary importance.

Variations were made in hydraulic and solids handling to determine system responses. The analysis of the data indicates that the flotation circuit is relatively insensitive to these changes. At increased solids loading and flows, more careful attention is required to balance the system. Due to the relatively inexpensive capital costs of the flotation system and possible scale-up problems, a design basis of 10 minutes hydraulic residence time per stage, feeding a maximum of 15% solids is recommended. The design residence time should be the same for each added cleaner stage. The actual residence time will be slightly greater for the two cleaners and slightly lower for the rougher depending upon the amount of dilution water added.

Grade and Recovery

Throughout the study period the feed grade ranged from 65-95% $CaCO_3$. The concentrate grade ranged from 92-100% $CaCO_3$ when sludge recycle was employed. As discussed, concentrate grade appeared relatively insensitive to most system parameters. A concentrate grade of 92% was possible when the collector was selective. Excellent agreement between pilot and bench scale results was demonstrated for product grade. Slightly higher collector feed was required to maintain good recovery in the pilot system indicating an increased collector efficiency for the bench scale system. Incremental collector feed in the pilot system was obviously not as efficient, but was required for froth control.

Recovery was affected by a number of variables previously discussed, including; pulp pH, level and type of collector, residence time and silicate feed. Recovery was calculated using two methods, a weight balance and a mathematical equation.

In bench scale tests there was excellent agreement between methods for calculation. All tails and concentrate produced were dewatered and analyzed for calcium carbonate. A check comparison was also made for the feed samples. The formula for recovery is as follows:

$$R = \frac{100c(f-t)}{f(c-t)}$$

WHERE: R = Recovery in %
c = Concentrate grade
f = Feed grade
t = Tail grade

In using this formula, the flotation circuit must be considered as a single system.

Recoveries found in bench scale tests under optimum conditions were consistently 90-92%. In the pilot scale, recoveries of 75-80% were typical with poor agreement between the formula and gravimetric methods of recovery determination. The difference between methods was partially explained by solids lost from the circuit or accumulation within junction boxes. It has been shown that recovery is sensitive to operating conditions which are more difficult to control with the pilot system. It was impossible to feed all of the collector to the conditioning stage because of foaming. Although more collector per ton of feed solids was reported for the pilot scale, the loss in efficiency made comparison difficult.

A full-scale installation should provide more stable operating conditions allowing more efficient collector usage. The results obtained would indicate that under proper operating conditions, a minimum of 85% recovery should be possible.

Effect of Low Grade Feed

Most of the successful flotation tests were performed on sludge samples having a calcium carbonate feed grade in excess of 85%. Although the sludge will seldom be of lower quality, flotation of low grade sludge was undertaken for evaluation under extreme conditions. Unfortunately, sludge recycle failed concurrently with the seasonal rise in raw water turbidity. Pilot plant operation was discontinued in January, 1976; however, samples of the conventional plant sludge were collected on April 21. River water turbidity was 1,400 FTU, and settled feed to the treatment plant was 160 FTU. These conditions represent extremes not exceeded in 1975. Three mg/l of sodium aluminate and 0.75 mg/l of cationic polymer were fed as coagulants along with 95 mg/l of lime.

The calcium carbonate grade in the sludge collected for study was 65%. The sludge was carbonated to dissolve magnesium present, pressure filtered to 65% solids and reslurried with tap water for flotation study. Residual magnesium after treatment was 7 mg/gram dry cake, subtracting the contribution from the clay.

Flotation treatment and results are shown in Table 9. A product grade of 92% was obtained with a Dresinate TX-60 W feed of 7 lb/ton at a flotation pH of 9.0. Added silica appeared to reduce recovery without significantly affecting product grade.

It is impossible to evaluate the effects of the added coagulants, polymer and sodium aluminate. It is probable that improved results may be found in their absence. A considerable amount of activated carbon was present in the sludge. Although the effect on flotation has not been demonstrated, it is proposed that increased collector was required because of the activated carbon.

TABLE 9. FLOTATION RESULTS ON LOW GRADE CONVENTIONAL PLANT SLUDGE

Number	Feed		Chemicals Added (lb/ton)			% CaCO$_3$							% Recovery
	% Solids	pH	Silicate	Soda Ash	Dresinate	Feed	Tails	RoCon	#1 Cl.	#2 Cl.	#3 Cl.	#4 Cl.	
1	15	9.0	0	6	2.5	65.0					86.6		
2	15	9.0	1	6	2.5	65.0					85.2		
3	10	9.0	0	4	5.0	65.0	35.3			82.7	86.2		77
4	15	9.0	0	5	5.0	65.0	44.8			75.0	78.6		72
5	10	9.0	2	5	5.0	65.0	37.3				81.3		78
6[a]	15	9.0	0	5	5.0	65.0	42.8			79.1			74
7	10	9.0	1	7	7.0	65.0	36.7	71.6	81.9	85.4	91.2		73
8	10	9.0	2	7	7.0	65.0	38.5			83.9			75
9	10	9.0	4	6	7.0	65.0	40.8			87.1			70
10	10	9.0	0	6	7.0	65.0	44.3				87.5	92.0	61
11	10	9.0	2	6	7.0	65.0	55.5				91.4	92.2	37
12	10	9.0	4	6	7.0	65.0	50.1				90.6	92.0	50

[a] - Conventional plant sludge was not pretreated by carbonation

Bench scale tests were not closed cycled; thus tails from cleaner stages were not recycled to the processing stage. This method of testing reduces recovery with increasing cleaner stages as the data demonstrated. Earlier studies with higher grade feed sludges exhibited poor correlation between feed and product grade.

Froth flotation provided acceptable beneficiation to a sludge far lower in calcium carbonate content than would be expected at Johnson County. Product recovery, in full-scale operation, could be expected to exceed the 70-75% found in the lab study.

Flotation Tails

Initial observation of the recovery efficiencies indicated would appear confusing considering the relatively high percentage values of calcium carbonate in the tails. Review of a typical example will provide insight as to the various relationships making up recovery.

Consider a feed assay of 95%, concentrate assay of 98% and tails assay of 50% $CaCO_3$. Low recovery would be concluded when observing the relative high grade of the tails. The recovery equation predicts an 85% recovery. A graphical analysis of these values is shown as Figure 16. The histogram illustrates that while the calcium carbonate percentage in the tails is high, the relatively low 'other' content in the feed explains the high recovery found.

A silt-calcium carbonate sludge exhibits thickening and dewatering characteristics that are increasingly favorable as the calcium carbonate percentage increases. Thus, having tails with 30-40% calcium carbonate allows the sludge to be readily thickened and dewatered.

Flotation tails will contain 20-30% of the total sludge produced at a treatment flow of less than 0.5% of the water flow rate.

Thickening curves for several bench scale studies are presented in Figure 17. Leaf filter tests indicate that 3-5 $lb/ft^2/hr$ could be expected dewatering with a vacuum filter. Clarification studies indicate that a suspended solids content of 70 mg/l could be expected on the thickener overflow.

Grade and Recovery Sensitivity Analysis

The initial flotation studies were designed in hope that regression equations could be obtained that would quantify recovery and grade as a function of the various operating parameters.

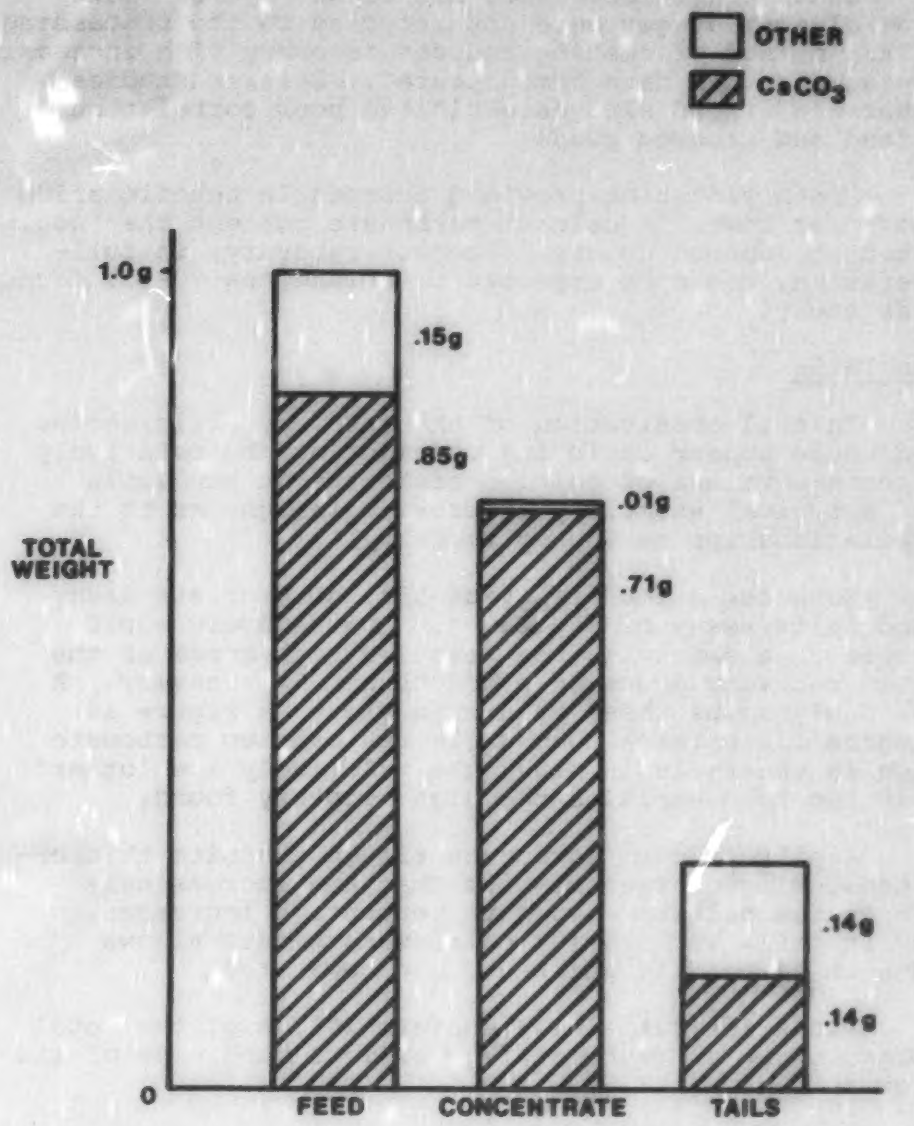


FIGURE 16. COMPARISON OF CALCIUM CARBONATE FRACTIONS IN INDICATED FLOTATION STREAMS.

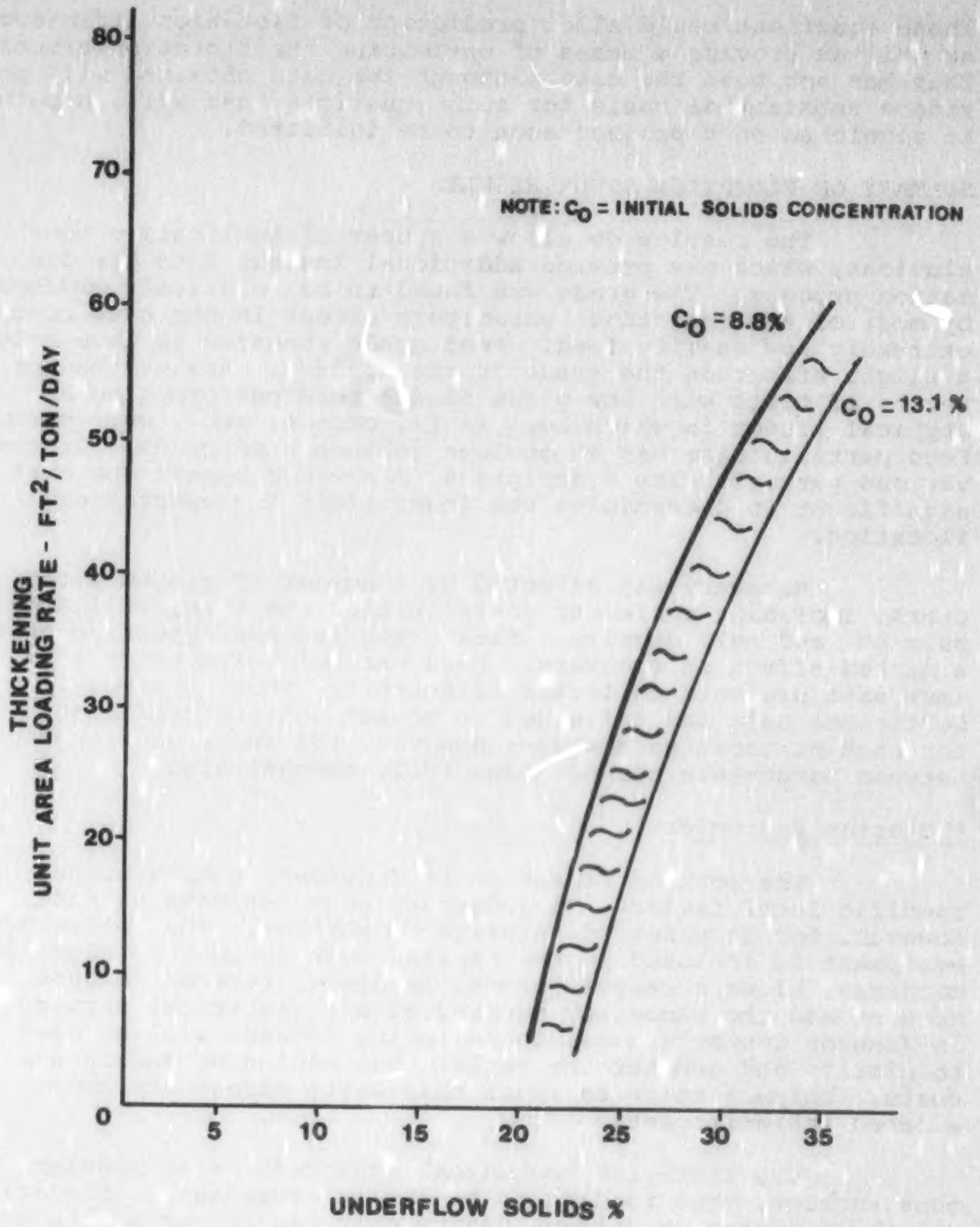


FIGURE 17 . THICKENING CHARACTERISTICS OF FLOTATION TAILINGS

These equations would allow prediction of flotation efficiencies as well as provide a means of optimizing the flotation process. This has not been the case although the data obtained will provide a substantial basis for such equations that will, hopefully, be developed on a project soon to be initiated.

SUMMARY OF FLOTATION STUDY RESULTS

The results do allow a number of qualitative conclusions, which may provide additional insight into the flotation process. The grade was found to be relatively unaffected by most of the operating parameters except in the case of the extremely low quality feed. Feed grade appeared to have only a slight effect on the grade of the product. Again, the one series of tests with low grade sludge were performed on an atypical sludge in which coagulants, carbon, etc., were present. Feed particle size has an obvious influence on grade. Of the various particle size descriptors, D_{10} would appear the most significant in determining the lower limit for successful flotation.

Recovery was affected by a number of system parameters, including collector concentration and type, silica feed, pulp pH, and pulp density. Feed grade did not appear to have a marked effect on recovery. Feed particle size below a minimum size prevents collector selectivity; thus, recovery. Sufficient data was collected to select optimum conditions for each of these parameters; however, the interrelationship between parameters has not been fully demonstrated.

Flotation Economics

The cost of flotation is dependent upon a number of specific local factors. A budgetary cost estimate is made, however, for purposes of relative comparison. The following equipment is included in the capital cost estimate: flotation machines, blowers recycle pumps, samplers, reagent feeders, housing and the necessary mechanical and electrical service. In Johnson County's case, the existing lagoons will be used to clarify and dewater the tails, thus adding no additional costs. Polymer costs to treat this waste stream are considered insignificant.

The flotation mechanical equipment is of modular construction, thus tending to be easily expandable. Flotation will be required in Johnson County only two-thirds of the year, reflecting reduced labor and power costs. Historical water quality data indicate that a sludge grade acceptable for recalcination without the need for beneficiation can be expected at least four months of the year. Table 10 summarizes the flotation costs assuming a design and operating capacity

TABLE 10. FLOTATION ECONOMICS AT 50 TONS/DAY CALCIUM OXIDE

	$/YEAR	$/TON OF CaO
CAPITAL COST		
$250,000 (7% for 20 Years)	23,258	1.42
LABOR		
12 Hours/Day @ $6/Hour	17,345	1.06
POWER		
175 HP @ $0.02/KWH 2/3 of the Year	15,232	0.78
CHEMICALS		
5 #/Ton of Dresinate	16,753	1.02
2 #/Ton of Soda Ash		
TOTAL	$ 67,004	$ 4.28

of 50 tons/day. All costs are expressed in terms of the final product, calcium oxide.

For comparative purposes, costs for 80 and 160 tons/day plants are also made and included in Figure 18. Unit labor and capital costs are greatly reduced with the large production facilities.

The system estimated includes three cleaner stages. This additional cost may be justified during high water turbidity. The extra stage may be bypassed to reduce power costs when not required. Table 11 illustrates the need for additional cleaner stages for the typical and low feed grade sludge conditions.

Chemical costs will vary, but the effect will be minor as they are only a minor portion of the total cost.

Additional Process Economic Considerations

A budgetary cost analysis to include the various unit operations required to implement the process at Johnson County follows. The units are designed for maximum plant production of 50 MGD and include:

1) Sludge Carbonation - the cost estimate includes sludge piping, carbonation cells, piping and transport of kiln exhaust gas, and pumping to and from the cells.

Design Flow	150 GPM
Retention Time	60 min.
Alkalinity	8,000 mg/l as $CaCO_3$
Solids	10%

2) Carbonated Sludge Thickener - The thickener is designed based on thickening studies reported earlier.

Design Loading	50 ft^2/ton/day
Surface	4,500 ft^2
Diameter	75 ft

3) Vacuum Filter - The cost estimate for the vacuum filter does not include housing, as this has been provided in the flotation circuit. A mechanical conveyor has been included to transfer the filter cake to the flotation conditioning cells.

Design Loading	15 lb/ft^2/hr
Surface Area	500 ft^2

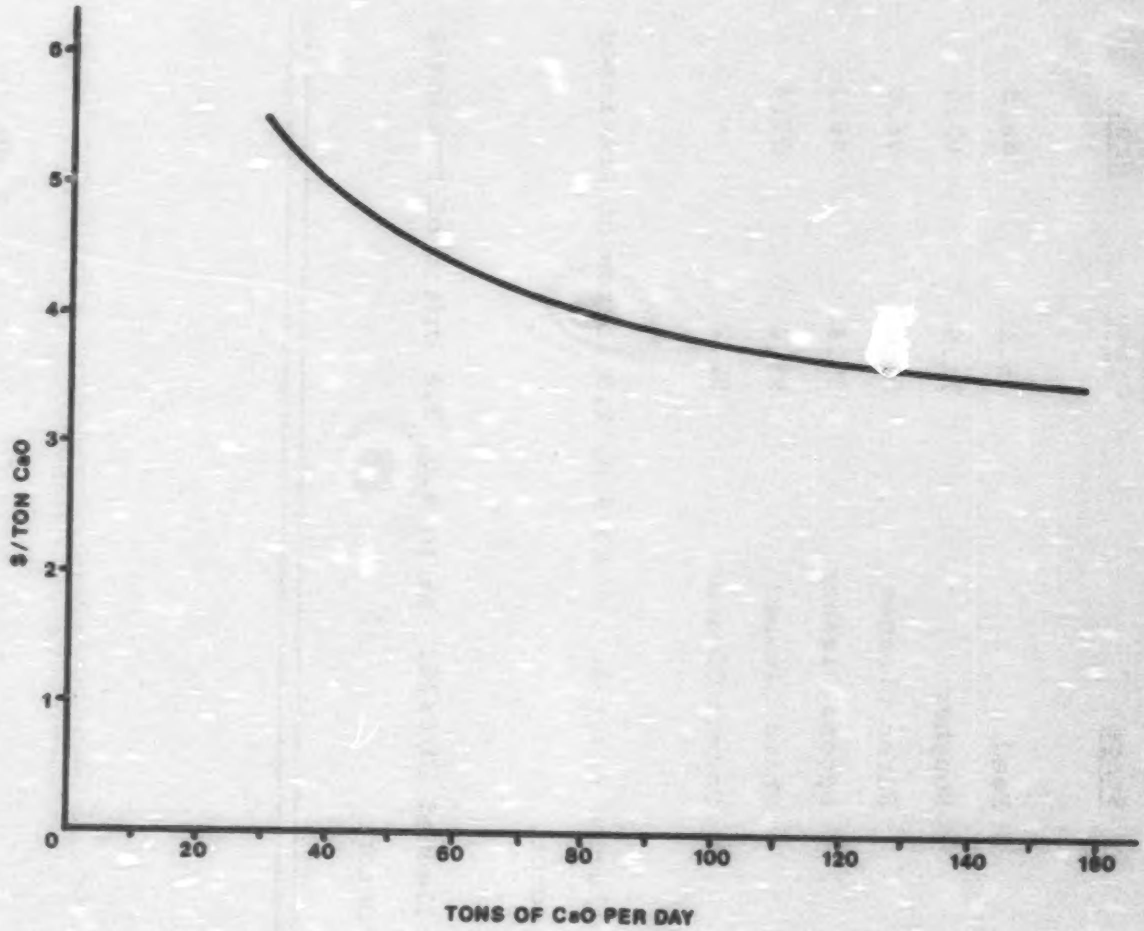


FIGURE 18. FLOTATION COSTS AS RELATED TO TONNAGE PROCESSED.

TABLE 11. EFFECT OF ADDITIONAL CLEANING STAGES ON PRODUCT GRADE

Stage	Minimum[a] Grade	Typical[b] Grade
Feed	65.1	88.3
Rougher	71.6	92.8
First Cleaner	81.9	96.0
Second Cleaner	85.4	96.9
Third Cleaner	91.2	97.4
Fourth Cleaner	92.2	-

[a] Sludge collected 4/30/76. pH to 9.0, 7.0 lb/ton of Dresinate TX-60 Collector.

[b] Sludge collected 10/8/75. pH to 9.0, 2.8 lb/ton of Dresinate TX-60 Collector.

4) Product Centrifuge - The centrifuges are designed for feed solids of 8-10%, almost pure calcium carbonate, at a total flow rate of 250 GPM. Two centrifuges are planned.

5) Tails Dewatering - This will be accomplished in the existing sludge lagoons. Overflow supernatant will be recycled back to the plant influent. Lagoon cleaning, hauling and disposal costs should be reduced by 80%.

6) Rotary Lime Kiln, Feed, and Storage Facilities - Actual kiln size will depend upon future plant expansion considerations, however, a 50 ton/day kiln is assumed. The necessary facilities for coal storage, pulverizing, and feed are included as are the necessary air pollution control devices.

Table 12 summarizes the capital costs for all necessary facilities including flotation. The total capital cost for facility implementation is $3,727,600 including engineering and contingencies. All capital and operating costs are expenses against lime production for economic comparison. Table 13 summarizes these.

The unit costs were compared for average and full-scale facility operation. As the average water production increases, the unit costs will decrease substantially.

Energy requirements of the recalcining process require careful consideration as to fuel source. The cost differential for the various fuel sources is significant. Natural gas in the Kansas City area is, at best, only seasonally available, thus another fuel source is required. We used $32/ton as the cost for coal. Most commercial lime producers are currently using coal in winter months when gas supplies are interrupted. The storage, pulverizing, and feed facilities are easily operated and relatively uncomplicated. Coal as a secondary, if not primary fuel is proposed. Using coal as fuel, the total cost per ton of lime ranges from $42.88 to $68.77 dependent upon lime production.

Implementation of the magnesium recycle, flotation, and lime recovery will reduce costs in a number of ways. First, sludge disposal costs will be reduced by 80%, or $64,000/year. This cost savings can be expected to increase yearly. Table 14 summarizes chemical costs which would be greatly reduced or eliminated.

TABLE 12. SUMMARY OF CAPITAL COST
JOHNSON COUNTY, KANSAS

Item		Cost
1)	Sludge Carbonator Cells	50,000
2)	Carbonated Sludge Thickener	175,000
3)	Vacuum Filters	215,000
4)	Product Centrifuges	200,000
5)	Rotary Lime Kiln	1,600,000
6)	Piping (15%)	336,000
7)	Electrical and Instrumentation (20%)	448,000
	Sub-Total	$3,024,000
8)	Engineering and Contingencies (15%)	453,600
	Sub-Total	$3,477,600
9)	Flotation Circuit[a]	250,000
	TOTAL	$3,727,600

[a] Total cost including engineering and contingencies has been calculated prior.

TABLE 13. LIME RECOVERY COSTS
50 tons/day CaO

(Includes all additional plant facilities)

	Annual Cost ($/yr)	Water Production 30 MGD	($/ton CaO) 60 MGD
CAPITAL COSTS:			
3,727,600 @ 7% for 30 yrs	297,582	32.61	16.30
LABOR COSTS:	91,500	10.03	5.01
4 Operators @ $12,000/yr			
3 Ass't Operators @ $9,000/yr			
1 Maintenance @ $12,000/yr			
0.25 Management @ $18,000/yr			
REPAIRS & MAINTENANCE		2.00	1.00
FUEL:			
Natural Gas ($1/million BTU)		9.00	9.00
Fuel Oil ($2.20/million BTU)		19.80	19.80
Coal ($1.25/million BTU)		11.25	11.25
POWER:			
Electricity	108,307	11.86	8.30
CHEMICALS:			
Flotation Reagents	8,376 - 16,753	1.02	1.02
TOTAL[a]	627,526 to 782,560	68.77	42.88

[a] - Assume use of coal

TABLE 14. CHEMICAL COST SAVINGS

Chemical	Average Annual Dosage (mg/l)	Tons/yr (Assume 30 MGD Production)	$/yr
Carbon Dioxide	20.4	930	35,354
Chlorine	5.4[a]	246	49,255
Alum	1.5	68	8,620
Sodium Aluminate	2.0	91	37,580
Polymer	1.6	73	65,528
			$196,336

[a] Prechlorination only

(NOTE: Based on 1975 chemical usage)

It is doubtful that these chemicals could be totally eliminated; therefore, an 80% reduction is assumed or $157,068.

Approximately 20% of the lime recalcined will be in excess of water treatment requirements; thus, available for sale. Implementation of the magnesium process will require a lime feed of 165 mg/l as opposed to the 135 mg/l presently fed.

Table 15 compares the present method of water treatment with the proposed process for directly affected cost elements. Implementation of lime recovery at the initial average production of 30 MGD produces an annual additional cost of $105,542; however, as the facilities are fully utilized, a cost savings of $261,408 results. Additional chemical cost savings may be realized in that a reduced soda ash feed is required when additional magnesium carbonate hardness is removed, as would be the case with the process studied. An average water production of 36 MGD would be required for the process to be economically favorable considering only the data shown in Table 15.

Design of facilities to operate more nearly at capacity on start-up would reduce or eliminate the additional annual costs. Water plant sludge could be stored to reduce peak requirements and facility sizing. The economic data were developed for comparative purposes and do not necessarily represent the least cost facility design.

TABLE 15. ECONOMIC COMPARISON OF PRESENT AND PROPOSED TREATMENT

Comparable Cost Elements	Annual Cost ($/yr)			
	30 MGD Production		60 MGD Production	
	Present	Proposed	Present	Proposed
Lime	237,041	627,526	474,002	782,560
Additional Chemical Costs[a]	157,068	- 0 -	314,136	- 0 -
Sludge Hauling Costs[a]	80,000	16,000	160,000	32,000
Excess Lime Sales[b]	- 0 -	〈63,875〉	- 0 -	〈127,750〉
TOTAL	$474,109	$579,651	$948,218	$686,810
NET ANNUAL SAVINGS		〈105,542〉		261,408

[a] - See Table 14, assumes 80% reduction

[b] - Assumes sales at $35/ton, 20% excess

The sale of excess magnesium, which may add to the cost savings, will be discussed in the next section.

Magnesium Recovery

As noted previously in Table 1, the magnesium content of the raw water averaged 62 mg/l considering the average ratio of well to river water. Dependent upon coagulation pH, up to 52 mg/l as $CaCO_3$ would be precipitated under normal operation. Assuming a 10% loss in the sludge, approximately 390 lb/MG of magnesium, expressed as calcium carbonate, can be recovered.

Magnesium can be recovered from the saturated recycle stream in a number of forms. In 1946, the Department of the Interior reported a process for magnesium carbonate recovery by using air to strip out the carbon dioxide causing precipitation.(31) Controlling the temperature between 35-45°C produced magnesium carbonate trihydrate ($MgCO_3 \cdot 3\ H_2O$) having a solubility of approximately 2.2 g/l. Boiling the liquor precipitates basic magnesium carbonate ($4\ MgCO_3 \cdot Mg(OH) \cdot 4\ H_2O$) which has a solubility of approximately 0.1 g/l. Either of the compounds can be converted to various grades of MgO by heating to 550°C or higher.

In a 1972 market survey, Innes (32) reported that the United States consumption of basic carbonate had stabilized at an annual level of 8,000 tons. Most of this consumption is in the drug, rubber and plastics industries. The market for magnesium oxide is greatly expanded representing a considerable market for a significantly lower grade product.

Preliminary results of a market survey in progress indicate a considerable market for light burned magnesium oxide. (33) By controlling the temperature of calcining to approximately 550°C the magnesium oxide produced is quite reactive. Uses and typical market prices for the product include:

Use	Cost ($/ton)	Approximate Market (tons/yr)
Electrical Insulation	800	10,000
Refractories	200	Large
Electrical Steel	900	1,000-2,500
Rubber	740	Unknown
Pharmaceutical	1460[a]	Unknown

This survey reports magnesium supplies to be 'tight' with concern over a possibility of shortages developing.

Production of the trihydrate allows only partial recovery of the magnesium because of its relatively high solubility. Recycle of this process stream can be accomplished so that it is not wasted from the system. Recycle to the raw water will require lime for reprecipitation, although it may be useful as a coagulant for those raw waters with only moderate magnesium levels. One flow scheme proposed utilizes dilution water prior to carbonation to control solids. In this case, the water from the magnesium production process could be used for this purpose, reducing lime requirements.

Magnesium Carbonate Production Pilot Studies

In the operation of the magnesium production portion of the pilot plant, the recycle stream was valved through hot water heat exchanger to the flotation cells. The recycle rotameter was used to measure flows of the liquor. The temperature was controlled by the water heater thermostat.

The flotation cells, after thorough cleaning, were used to strip carbon dioxide from solution, precipitating the magnesium carbonate trihydrate. The cells used had a volume of 135 gal. providing a residence time of 22-45 minutes dependent upon flow rate.

Recycle of precipitated material was maintained at a flow rate of 1 GPM and was provided to assist precipitation by seeding the reactions.

Pilot scale studies were performed in June, July, August, and November. Influent alkalinities ranged from 3,400-6,800 mg/l. As previously discussed, the low alkalinities resulted from the mechanical sludge collection deficiency in the Permutit basin. Higher sludge solids in the carbonator feed would have produced respectively higher alkalinities; unfortunately, increased solids feed was a mechanical impossibility.

After aeration, the alkalinity ranged from 2,800-3,000 mg/l as $CaCO_3$. During the November study, approximately 54 lb/hr of the product were precipitated. Vacuum filtration produced a 40% solids cake. The filtration characteristics were excellent producing in excess of a 1 in. thick, easily discharged filter cake.

All products were lower in purity than expected. The primary impurity was calcium carbonate which was carried over in the thickener supernatant. Either a sand or diatomaceous earth filter prior to the heat exchanger would have eliminated or greatly reduced this problem.

The silica level in the recycle stream was reflected in the product. Filtration would have little effect in reducing values found. However, greatly reduced levels would be expected when production, not recycle was employed. The precipitated product was slightly brown in color, resulting from the organic color in the solution. The color can be removed by contacting the magnesium bicarbonate liquor with activated carbon as reported in previous studies. Table 16 summarizes the results of the four pilot scale production studies.

Laboratory Studies

Samples of the recovered magnesium carbonate were treated in the laboratory to determine how product purity might be improved as well as to develop additional unit process design data.

A sample of magnesium carbonate produced in the pilot plant was redissolved using pure carbon dioxide producing a solution with a magnesium concentration of approximately 10,000 mg/l as $CaCO_3$. This solution was used in all subsequent studies.

Prolonged settling insured that only a clear solution was used in the precipitation studies. A laboratory scale precipitator reactor was fed the clear magnesium solution controlling such variables as temperature, air flow and mixing conditions, and the presence of preformed magnesium carbonate crystals. The magnesium carbonate produced was evaluated for purity and the precipitate used for bench scale thickening and dewatering studies.

Sufficient settling of the magnesium bicarbonate liquor prior to precipitation of the magnesium dramatically improved the quality of the product. A comparison of impurities contained in the product produced in laboratory and pilot studies follows:

Contaminant (mg/g)	Pilot	Laboratory
Silica	34.0	0.5
Calcium	73.0	3.4
Iron	0.9	1.7

The improved quality of the laboratory produced magnesium carbonate supports the conclusion that filtration of the magnesium bicarbonate liquor will dramatically improve product purity. Figure 19 illustrates thickening characteristics of the magnesium carbonate trihydrate. Leaf vacuum filter tests indicated filter loading rates in excess of 100 lb/ft^2/hr are possible producing a 40% solids cake.

TABLE 16. SUMMARY OF MAGNESIUM PRODUCTION STUDIES

Date	Flow Rate (GPM)	Temperature (°C)	Alkalinity (mg/l as $CaCO_3$)		Product Analysis (mg/g)			
			In	Out	Mg	Ca	Si	Fe
6/11	3	40	3922	2407	170	-	-	-
7/12	6	40			109	95	-	-
8/28	3	39	3400	3175		54	-	-
11/20-21	5	41	6700	3200	141	60	34	0.88

- denotes that analysis not performed

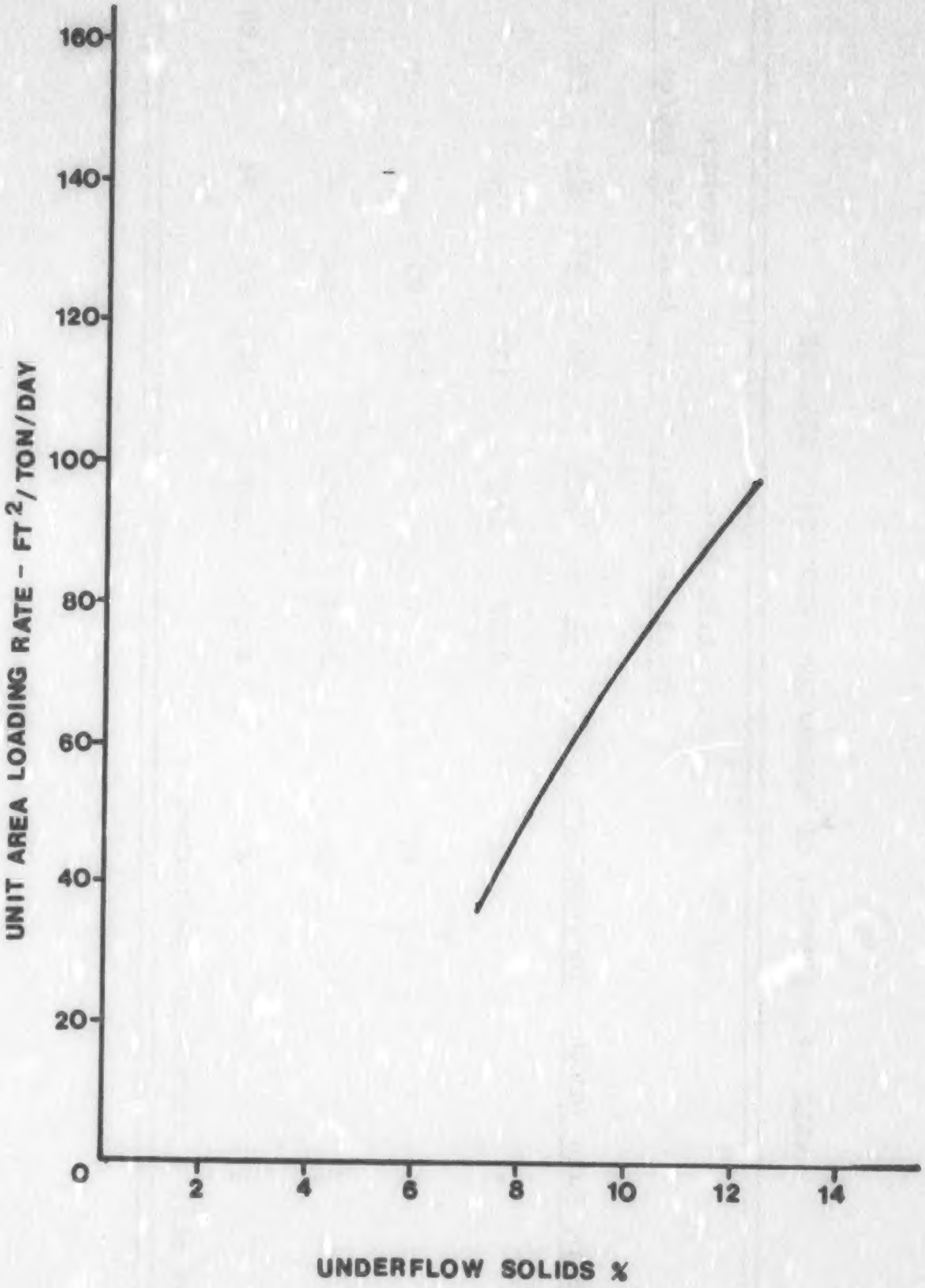


FIGURE 19 . THICKENING CHARACTERISTICS OF $MgCO_3 \cdot 3H_2O$

A summary of design criteria developed from the laboratory studies is as follows:

1) The temperature for maximum precipitation of magnesium carbonate trihydrate was 45°C. Above or below this temperature a slight increase in solubility resulted.

2) An air flow rate of 4 ft^3/gallon of liquid was required to optimize tankage and blowers.

3) Heat exchanger surfaces must be designed to reduce scaling from the saturated magnesium solution.

Economics of Magnesium Recovery

Figure 20 illustrates the units required to produce MgO from the recycled magnesium bicarbonate liquor. Heat exchange, to warm the liquor to 45°C, is provided by scrubbing the multiple hearth furnace exhaust gases. The CO_2 partial pressure of the gases will reduce precipitation problems.

The capital cost for three tons per day MgO production is shown in Table 17. Annual costs are summarized in Table 18. The cost per ton of MgO produced is estimated at $155.

The lime kiln or multiple hearth furnace can possibly be used for both lime recalcining and MgO production. The magnesium carbonate thickener can be slightly increased in size to allow storage of material for a four-day period. Lime recalcining would operate four days and store calcium carbonate one day when the kiln is used to produce MgO. Sufficient storage is available in the calcium carbonate thickener to allow the proposed operation. The extent of MgO contamination can be evaluated in pilot studies.

Using the furnace or kiln for dual purposes would allow a capital cost savings of approximately $400,000 along with an estimated labor savings of 10,000 per year. These savings would reduce the cost of producing MgO to approximately $117 per ton. Additional lime feed is required to precipitate all of the magnesium. The added cost for this additional lime is for fuel costs only as the lime recovery facilities will adequately handle the additional capacity. Assuming an additional feed of 50 mg/l of CaO and a fuel cost of $11.25 per ton of CaO, the added cost per MG treated is $2.34. At a MgO production rate of 0.08 tons per MG of water treated, the result is an additional cost of $30 per ton of MgO. Therefore, a cost range of $147 to $185 per ton of MgO can be expected.

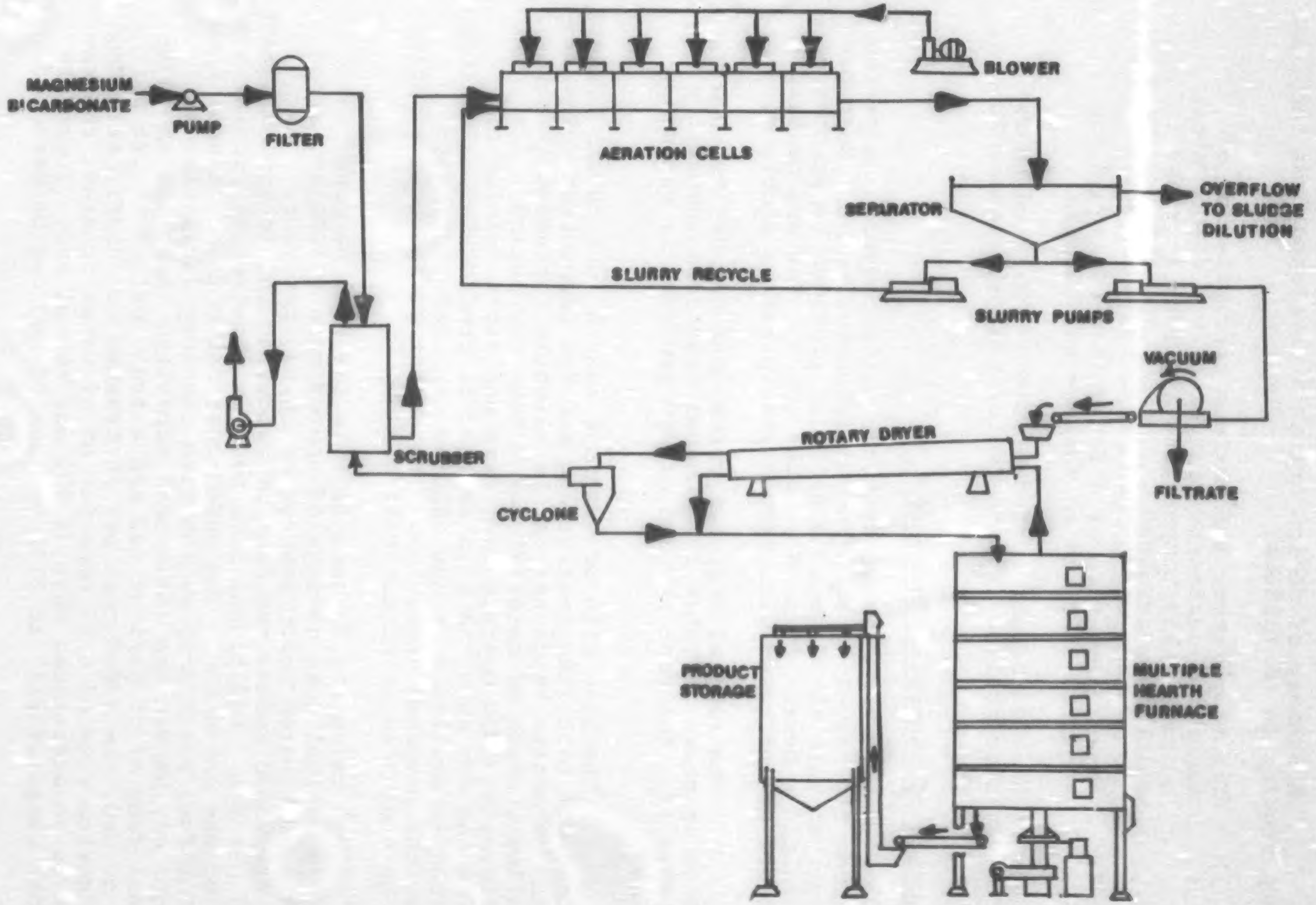

MAGNESIUM
BICARBONATE
PUMP
FILTER
AERATION CELLS
BLOWER
SEPARATOR
OVERFLOW
TO SLUDGE
DILUTION
SLURRY RECYCLE
SLURRY PUMPS
VACUUM
FILTRATE
SCRUBBER
ROTARY DRYER
CYCLONE
PRODUCT
STORAGE
MULTIPLE
HEARTH
FURNACE

FIGURE 20. MgO PRODUCTION FACILITIES

TABLE 17. CAPITAL COST FOR 3 TONS/DAY
OF MgO PRODUCTION

Item	Cost ($)
Aeration Cells (60 minute retention)	50,000
Thickener (30 ft diameter)	60,000
Vacuum filter (9 ft^2)	25,000
Rotary Drier	115,000
Multiple Hearth Furnace (includes (scrubber, storage, etc.)	333,000
Piping (15%)	87,500
Electrical (20%)	116,600
Sub-total	787,100
Engineering & Contingencies (20%)	157,420
TOTAL	$944,520

TABLE 18. SUMMARY OF ANNUAL COST
FOR MgO PRODUCTION

Element	Annual Cost ($/yr)
Capital Cost Recovery (30 years @ 7%)	75,372
Maintenance (3% of Capital Cost)	28,335
Fuel (6 million BTU/ton MgO)	14,454
Electricity (3¢/KWH)	23,224
Labor (4160 hrs/yr @ $7/hr)	29,120
TOTAL ANNUAL COST	$170,505

COST PER TON MgO - $155

Magnesium recovery can be added without affecting the existing processes. It is, therefore, recommended that recovery be delayed until Dayton has conducted the proposed market survey and economic analysis. It is very unlikely that magnesium recovery will be more attractive in Johnson County than Dayton, as Dayton is in close proximity to a considerable magnesium market and Dayton's product can be produced in a purer form at a lower cost. This results primarily from Dayton's clear groundwater source containing little or no objectionable product contaminants and larger production capability.

Recycle of magnesium as a coagulant, as opposed to precipitation of all magnesium present, will result in reduced lime requirements. As the market for the product develops and experience with recovery indicates economic justification, recovery facilities can be added.

SECTION VI

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WEEKLY SUMMARY
PILOT PLANT OPERATING DATA
JOHNSON COUNTY, KANSAS

February & March

Week Ending	Flow (MGD)	Basin Influent				Chemicals Added			Rapid Mix pH	Basin Effluent					Carbonator						Thickener Underflow	
		Total Alk.	Ca Hard.	Mg Hard.	Turb. FTU	Lime mg/1	Polymer mg/1	Recycle mg/1		pH	Ca Hard.	Mg Hard.	Total Turb. FTU	Acid Turb. FTU	Inf. pH	Dry Wt. Solids	CO_2 cfm	Sludge gpm	Effluent		gpm	% Dry Wt Solids
		--mg/1 as $CaCO_3$--									mg/1-$CaCO_3$								pH	Total Alk.		
2/7/75	2	200	228	50	48	207	0.20	64	11.29	11.2	127	35	5.92	1.25	11.23		9.65		7.2	7719	2.6	15.6
2/14/75	2	219	251	59	20	204	0.12	28	11.26	11.1	144	23	5.8	1.19	11.17		5.44		7.2	8020	1.0	21.15
2/21/75	2	214	246	55	24	188	0.10	16	11.35	11.2	173	19	3.53	0.51	11.16	6.2	4.43	6.15	7.3	6919	2.2	12.11
2/28/75	2	189	209	53	43	163	0.20	31	11.19	11.1	136	29	4.4	1.21	11.15	7.9	8.0	9.4	7.	7632	5.52	12.54
3/7/75	2	206	234	69	30	166	0	29	11.22	11.1	146	36	4.0	1.18	11.12	6.3	6.25	8.16	7.3	6943	7.22	8.5
3/14/75	2	206	229	68	17	158	0	31	11.39	11.2	147	36	4.7	1.5	11.3	6.7	7.69	8.5	7.2	8086	5.06	10.5
3/21/75	2	204	234	66	19	129	0	34	11.37	11.3	135	46	3.6	0.8	11.3	7.14	7.0	8.0	7.2	7305	3.07	12.8
3/28/75	2	205	232	69	25	123	0.02	20	11.38	11.3	119	43	5.6	0.8	11.3	7.3	5.4	7.7	7.2	5734	4.54	15.6

APPENDIX A

WEEKLY SUMMARY
PILOT PLANT OPERATING DATA
JOHNSON COUNTY, KANSAS

April & May

Week Ending	Flow (MGD)	Basin Influent				Chemicals Added			Rapid Mix pH	Basin Effluent					Carbonator						Thickener Underflow	
		Total Alk.	Ca Hard.	Mg Hard.	Turb. FTU	Lime mg/l	Polymer mg/l	Recycle mg/l		pH	Ca Hard.	Mg Hard.	Total Turb. FTU	Acid Turb. FTU	Inf. pH	Dry Wt. Solids	CO_2 cfm	Sludge gpm	Effluent		gpm	% Dry Wt Solids
		--mg/l as $CaCO_3$--									mg/l-$CaCO_3$								pH	Total Alk.		
4/4/75	2.2	191	204	58	47	133	0.05	10	11.23	11.3	92	43	9.4	3.3	11.1	9.4	2.6	4.9	6.99	3621	2.4	10.7
4/11/75	3.0	193	200	63	40	172	0.04 (847A) 0.71 (607)	4	11.11	10.9	80	40	14.4	3.1	10.77	9.0	1.03	5.6	6.95	2110	3.1	12.3
4/18/75	2.0	180	181	57	43	161	0.17 (847A) 0.93 (607)	17	11.17	11.1	75	37	12.3	1.55	10.83	8.7	3.51	7.54	7.09	3429	1.0	13.7
4/25/75	2.0	175	177	50	56	168	0.22 (847A) 1.66 (607)	17	11.25	11.2	82	29	23	2.3	10.87	6.6	4.6	7.8	7.15	3756	2.4	10.9
5/2/75	2.0	170	179	57	48	169	1.58 (607)	13	11.13	11.1	90	25	18.7	1.66	10.83	6.2	5.3	6.1	7.06	4638	3.3	10.7
5/9/75	2.0	177	196	58	29	196	0.45 (847A)	18	11.12	11.1	123	22	19.6	2.22	10.79	6.8	5.2	7.1	7.19	5125	2.9	12.0
5/16/75	2.0	143	158	65	24	201	0.45 (847A)	26	11.12	11.1	126	15	12.5	1.42	10.75	5.7	7.2	7.3	7.2	7010	3.5	9.7
5/23/75	2.0	152	172	70	19	215	0.29 (847A)	44	11.00	11.0	130	18	15.8	1.00	10.39	5.0	9.0	7.8	7.13	7400	3.3	9.3
5/30/75	2.0	144	159	56	54	221	0	34	11.05	11.0	118	24	12.9	1.46	10.65	4.2	7.4	7.9	7.11	6460	3.5	9.0

APPENDIX A

WEEKLY SUMMARY
PILOT PLANT OPERATING DATA
JOHNSON COUNTY, KANSAS

June & July

Week Ending	Flow (MGD)	Basin Influent				Chemicals Added			Rapid Mix pH	Basin Effluent					Carbonator						Thickener Underflow	
		Total Alk. --mg/l as $CaCO_3$--	Ca Hard.	Mg Hard.	Turb. FTU	Lime mg/l	Polymer mg/l	Recycle mg/l		pH	Ca Hard. mg/l-$CaCO_3$	Mg Hard.	Total Turb. FTU	Acid Turb. FTU	Inf. pH	Dry Wt. Solids	CO_2 cfm	Sludge gpm	Effluent pH	Effluent Total Alk.	gpm	% Dry Wt Solids
6/6/75	2.0	137	145	42	74	183	0	22	11.01	11.0	108	16	16.0	2.93	10.84	5.6	7.2	8.1	7.2	5660	3.4	11.2
6/13/75	2.0	137	137	45	69	227	2.7 (607)	24	10.99	11.1	113	17	14.4	1.83	10.84	5.7	8.3	8.4	7.1	5870	5.1	11.6
6/20/75	2.0	145	150	48	29	306	0.34 (607)	19	10.96	10.9	115	14	16.2	1.79	10.79	4.7	7.8	8.5	7.1	5040	3.3	9.6
6/27/75	2.0	133	143	43	65	250	0.2 (607)	18	10.99	10.9	146	13	15.7	2.9	10.76	5.4	7.4	7.9	7.2	5270	3.8	8.1
7/4/75	2.0	126	137	42	62	210	0	18	11.1	11.0	164	14	15	4.3	10.8	4.7	6.0	7.8	7.2	4600	3.0	8.2
7/11/75	2.0	133	151	43	38	176	0	19	10.9	11.0	136	16	18	2.9	10.6	5.4	6.8	7.7	7.2	6200	4.3	6.4
7/18/75	2.0	137	169	52	33	204	0	15	10.9	10.8	134	17	22	3.0	10.5	4.3	5.2	7.5	7.2	4750	4.1	7.1
7/25/75	2.0	153	183	45	23	243	0	5	10.9	10.9	139	14	23	1.9	10.5	4.0	2.9	2.9	7.0	3860	1.9	6.3

APPENDIX A

WEEKLY SUMMARY
PILOT PLANT OPERATING DATA
JOHNSON COUNTY, KANSAS

August & September

Week Ending	Flow (MGD)	Basin Influent				Chemicals Added			Rapid Mix pH	Basin Effluent					Carbonator						Thickener Underflow	
		Total Alk.	Ca Hard.	Mg Hard.	Turb. FTU	Lime mg/l	Polymer mg/l	Recycle mg/l		pH	Ca Hard.	Mg Hard.	Total Turb. FTU	Acid Turb. FTU	Inf. pH	Dry Wt. Solids	CO_2 cfm	Sludge gpm	Effluent		gpm	% Dry Wt. Solids
		—mg/l as $CaCO_3$—									mg/l-$CaCO_3$								pH	Total Alk.		
8/4/75	2.0	134	165	46	33	272	0	19	10.9	10.9	135	10	20	3.3	10.5	4.0	2	7.5	7.0	5222	3.6	6.0
8/11/7	2.0	119	139	56	28	140	0	16	11.0	10.9	171	13	13	2.2	10.5	3.5	3	7.7	6.8	4130	3.5	5.5
8/18/7	2.0	136	158	60	16	216	0	20	10.9	10.7	137	14	10	1.6	10.4	3.4	3	7.1	7.0	3950	2.4	9.3
8/25/75	2.0	147	189	63	30	290	0	25	11.0	10.9	151	14	14	1.9	10.6	3.1	4	7.9	7.1	3683	1.0	8.6
9/1/75	2.0	144	167	49	24	336	0	17	11.0	10.8	139	14	23	2.3	10.6	2.7	4	6.8	7.1	3961	0.7	16.3
9/8/75	2.0	148	199	64	36	321	0	13	11.0	10.9	165	17	24	2.7	10.6	3.2	4	7.9	7.0	3866	3.4	6.0
9/15/75	3.6	134	173	48	49	231	0	13	11.2	11.1	155	16	17	2.6	10.9	3.8	6	8.8	7.0	3829	2.1	15.1
9/22/75	4.0	174	217	49	37	186	0	17	11.2	11.0	135	24	29	4.3	10.8	4.8	13	11.0	6.7	4332	2.1	13.7
9/29/75	2.9	155	191	61	40	195	0	20	11.2	11.1	135	26	24	3.8	10.9	5.1	5	8.6	7.1	5084	0.5	18.5

APPENDIX A

WEEKLY SUMMARY
PILOT PLANT OPERATING DATA
JOHNSON COUNTY, KANSAS

October & November

Week Ending	Flow (MGD)	Basin Influent				Chemicals Added			Rapid Mix pH	Basin Effluent					Carbonator						Thickener Underflow	
		Total Alk.	Ca Hard.	Mg Hard.	Turb. FTU	Lime mg/l	Polymer mg/l	Recycle mg/l		pH	Ca Hard.	Mg Hard.	Total Turb. FTU	Acid Turb. FTU	Inf. pH	Dry Wt. Solids	CO_2 cfm	Sludge gpm	Effluent		gpm	% Dry Wt Solids
		—mg/l as $CaCO_3$—									mg/l-$CaCO_3$								pH	Total Alk.		
10/6/75	2.6	153	194	52	18	163	0	16	11.2	11.1	128	29	12	1.6	11.0	6.7	7	5.5	7.0	5662	0.4	28.2
10/13/75	3.6	147	179	73	22	190	0	17	11.1	11.0	118	38	21	2.6	10.9	6.3	8	12.2	7.1	5339	3.1	18.6
10/20/75*	1.3					239			11.0					1.3								
10/27/75	3.9	192	235	71	11	227	0	21	11.1	11.0	124	49	7	0.8	10.8	8.3	8	11	7.0	6439	1.9	27.3
11/3/75	3.9	214	256	70	12	206	0	24	10.9	11.0	125	30	11	1.1	10.8	9.0	8	12.3	7.1	5509	1.0	32.0
11/10/75	3.8	204	238	72	21	234	0	28	11.0	11.0	136	38	8.7	1.0	10.8	7.7	10	13.2	7.1	6525	1.8	28.9
11/17/75	3.2	221	272	80	12	189	0	23	10.9	11.0	135	59	6.1	1.3	10.8	8.9	6	10.1	7.1	5128	1.2	20.0
11/24/75	4.5	223	264	70	12	228	0	14	11.1	11.1	133	53	9.8	1.6	10.9	10.4	7	6.3	7.1	6929	0.6	22.8

* Pilot Plant Off

APPENDIX A

WEEKLY SUMMARY
PILOT PLANT OPERATING DATA
JOHNSON COUNTY, KANSAS

December & January

Week Ending	Flow (MGD)	Basin Influent				Chemicals Added			Rapid Mix pH	Basin Effluent					Carbonator						Thickener Underflow	
		Total Alk. --mg/1	Ca Hard. as $CaCO_3$--	Mg Hard.	Turb. FTU	Lime mg/1	Polymer mg/1	Recycle mg/1		pH	Ca Hard. mg/1-$CaCO_3$	Mg Hard.	Total Turb. FTU	Acid Turb. FTU	Inf. pH	Dry Wt. Solids	CO_2 cfm	Sludge gpm	Effluent pH	Effluent Total Alk.	gpm	% Dry Wt Solids
12/1/75	4.3	200	252	67	25	217	0	27	11.2	11.2	143	55	5.8	1.3	11.0	9.0	6	11.5	7.0	4490	4.1	18.7
12/8/75	4.0	160	188	57	30	269	0	11	10.9	11.3	155	40	8.0	4.0	11.0	4.3	6	9.9	7.1	4938	5.1	9.9
12/15/75	2.0	187	210	72	22	370	0	27	11.1	11.1	133	45	4.3	1.9	11.0	7.3	7	9.3	7.1	6351	5.3	11.6
12/22/75	2.0	174	189	60	31	307	0	20	11.1	11.1	111	39	7.8	2.2	11.0	9.8	5	7.8	7.1	4555	1.2	21.9
12/29/75	2.0	154	186	54	24	288	0	10	11.1	11.2	113	39	7.5	2.5	11.1	8.7	4	7.1	7.1	4590	3.9	8.5
1/5/76	2.0	188	201	57	19	267	0	21	11.1	11.0	99	44	7.2	1.5	11.1	9.7	5	10.3	7.1	4201	2.6	18.6

APPENDIX A

WEEKLY SUMMARY
PILOT PLANT SOLIDS BALANCE
Johnson County, Kansas

APRIL & MAY

Week	Softening Basin Solids Production										Produced Total Solids				Carbonator Inf. Total Solids			Thickener Eff. Total Solids		
Ending	Turb.		Alk.		Raw Water			Recycled Magnesium			Turb.	$CaCO_3$	$Mg(OH)_2$	Total	Sludge gpm	% Dry Solids	lb/day	gpm	% Dry Solids	lb/day
					$CaCO_3$		$Mg(OH)_2$	$CaCO_3$		$Mg(OH)_2$	lb/day									
	mg/l	lb/day	mg/l	lb/day	mg/l	lb/day	lb/day	mg/l	lb/day	lb/day										
4/4/75	42	866	116	3801	15	260	151	10	355	113	866	4585	265	5717	4.9	9.4	5284	2.4	10.7	3197
4/11/75	39	976	118	5881	22	523	303	5.4	248	72	976	6123	375	7480	5.6	9.0	5998	3.1	12.3	3358
4/18/75	43	715	105	3507	20	336	195	18	643	170	715	4093	365	5056	7.4	8.9	7919	3.4	13.6	5400
4/25/75	56	941	100	3341	21	357	207	15	510	148	941	3711	[illegible]55	5146	7.8	6.6	6200	3.4	15.3	5401
5/2/75	50	827	95	3183	31	524	304	12	395	115	827	3612	419	4857	6.1	6.3	4557	3.4	10.7	4228
5/9/75	29	486	102	3398	36	593	344	17	572	166	486	3970	510	4966	7.1	5.0	5593	2.7	11.7	3708
5/16/75	25	412	68	2011	50	834	484	24	801	232	412	3083	716	4211	7.3	5.4	4725	3.5	9.8	4070
5/23/75	19	319	78	2588	55	915	531	39	1305	378	319	3829	909	5057	7.8	5.0	4742	3.3	9.3	3711
5/30/75	54	897	69	2317	32	537	311	31	1036	300	896	3352	611	4859	8.1	4.1	3955	3.5	9.0	3777

APPENDIX B

WEEKLY SUMMARY
PILOT PLANT SOLIDS BALANCE
Johnson County, Kansas

FEBRUARY & MARCH

Week Ending	Softening Basin Solids Production										Produced Total Solids				Carbonator Inf. Total Solids			Thickener Eff. Total Solids		
	Turb.		Alk.		Raw Water			Recycled Magnesium												
					$CaCO_3$		$Mg(OH)_2$	$CaCO_3$		$Mg(OH)_2$	Turb.	$CaCO_3$	$Mg(OH)_2$	Total	Sludge gpm	% Dry Solids	lb/day	gpm	% Dry Solids	lb/day
	mg/l	lb/day	mg/l	lb/day	mg/l	lb/day	lb/day	mg/l	lb/day	lb/day	lb/day									
2/28/75	42	695	117	3903	26	428	248	31	1030	298	695	4933	547	6175	9.2	7.6	8367	4.5	11.0	5484
3/7/75	30	498	131	4356	33	546	317	28	882	256	498	5238	573	6308	8.2	6.3	6160	7.2	8.5	6047
3/14/75	17	286	131	4356	32	536	311	28	929	270	286	5284	581	6151	8.5	6.7	6842	4.5	11.0	5898
3/21/75	16	310	129	4303	20	338	196	32	1077	312	310	5380	508	6199	8.0	7.1	5778	2.2	6.3	2883
3/28/75	25	417	130	4332	26	431	250	18	615	178	417	4947	428	5792	7.7	7.3		4.1	14.0	5639

APPENDIX B

WEEKLY SUMMARY
PILOT PLANT SOLIDS BALANCE
Johnson County, Kansas

JUNE & JULY

Week	Softening Basin Solids Production										Produced Total Solids				Carbonator Inf. Total Solids			Thickener Eff. Total Solids		
	Turb.		Alk.		Raw Water			Recycled Magnesium			Turb.	$CaCO_3$	$Mg(OH)_2$	Total	Sludge gpm	% Dry Solids	lb/day	gpm	% Dry Solids	lb/day
					$CaCO_3$		$Mg(OH)_2$	$CaCO_3$		$Mg(OH)_2$	lb/day									
Ending	mg/l	lb/day	mg/l	lb/day	mg/l	lb/day	lb/day	mg/l	lb/day	lb/day										
6/6/75	74	1229	68	2264	26	483	263	20	672	195	1229	2936	458	4623	8.0	5.6	5514	3.4	11.3	4530
6/13/75	69	1153	62	2054	29	489	284	22	743	216	1153	2797	299	4450	8.4	5.7	5703	3.1	11.6	4467
6/20/75	29	484	70	2335	34	569	330	17	581	168	484	2916	499	3899	8.5	4.7	4840	3.3	9.6	3782
6/27/75	64	1075	58	1768	29	488	293	17	572	166	1075	2340	449	3863	7.9	5.0	4715	3.8	8.1	3654
7/4/75	62	1041	51	1701	27	455	265	17	553	160	1041	2254	425	3720	7.8	4.7	4390	3.0	8.2	2943
7/11/75	38	633	58	1935	28	467	272	17	576	167	633	2511	439	3583	7.7	5.4	4959	4.3	6.4	3339
7/18/75	33	550	62	2-68	35	573	334	14	481	139	550	2549	473	3572	7.5	4.3	3832	4.1	7.1	3476
7/25/75*	24	384									384				2.9	4.0		1.9	6.3	

* Solids blanket lost on 7/22/75; $MgSO_4$ @ 25 lb/hour fed until July 30, 1975.

APPENDIX B

WEEKLY SUMMARY
PILOT PLANT SOLIDS BALANCE
Johnson County, Kansas

AUGUST & SEPTEMBER

Week	Softening Basin Solids Production										Produced Total Solids				Carbonator Inf. Total Solids			Thickener Eff. Total Solids		
	Turb.		Alk.		Raw Water			Recycled Magnesium			Turb.	$CaCO_3$	$Mg(OH)_2$	Total	Sludge gpm	% Dry Solids	lb/day	gpm	% Dry Solids	lb/day
					$CaCO_3$		$Mg(OH)_2$	$CaCO_3$		$Mg(OH)_2$	lb/day									
Ending	mg/l	lb/day	mg/l	lb/day	mg/l	lb/day	lb/day	mg/l	lb/day	lb/day										
8/4/75	33	548	59	1973	36	602	351	18	591	171	548	2564	522	3630	7.5	4.0	3600	3.6	6.5	2771
8/11/75	28	462	44	1402	43	706	412	16	519	150	462	2001	562	3026	7.7	3.8	3508	3.5	5.6	2354
8/18/75	16	274	61	2051	45	746	435	19	634	184	274	2684	641	3600	7.1	3.4	2890	2.6	9.3	2225
8/25/75	30	508	72	2412	49	809	472	23	762	221	508	3174	678	4359	7.9	3.1	2968	1.0	8.6	958
9/1/75	24	405	67	2302	35	573	334	16	548	159	405	3850	493	3748	7.4	2.7	2411	0.8	13.0	750
9/8/75	36	593	73	2426	46	761	444	13	434	126	593	2859	569	4022	7.9	3.4	3225	2.9	6.1	2101
9/15/75	49	820	59	1959	46	533	311	22	734	213	820	2592	524	2036	8.8	3.9	4093	2.1	16.7	3711
9/22/75	37	620	99	3307	25	417	243	34	1139	330	620	4446	573	5639	11.0	4.9	6493	2.1	16.2	3505
9/29/75	41	393	86	1639	44	422	246	42	801	232	393	2440	478	3311	5.1	5.1	4192	0.3	16.0	522

APPENDIX B

WEEKLY SUMMARY
PILOT PLANT SOLIDS BALANCE
Johnson County, Kansas

OCTOBER & NOVEMBER

Week	Softening Basin Solids Production										Produced Total Solids				Carbonator Inf. Total Solids			Thickener Eff. Total Solids		
Ending	Turb.		Alk.		Raw Water			Recycled Magnesium			Turb.	$CaCO_3$	$Mg(OH)_2$	Total	Sludge gpm	% Dry Solids	lb/day	gpm	% Dry Solids	lb/day
	mg/l	lb/day	mg/l	lb/day	$CaCO_3$		$Mg(OH)_2$	$CaCO_3$		$Mg(OH)_2$	lb/day									
					mg/l	lb/day	lb/day	mg/l	lb/day	lb/day										
10/6/75	18	176	78	1162	22	206	120	40	796	112	176	1149	177	1411	4.6	6.6	3640	0.2	28.2	770
10/13/75	23	276	72	1443	41	490	286	28	867	251	276	2603	537	3416	8.7	7.0	7340	2.5	21.7	8570
10/20/75*																				
10/27/75	12	138	118	2807	22	257	150	43	1034	300	138	3841	450	4347	9.1	8.4	9230	1.5	26.4	6361
11/3/75	12	284	139	6348	18	406	237	42	1983	575	284	8332	812	9428	12.3	9.1	11636	1.0	30.1	3444
11/10/75	21	677	129	8296	34	1067	622	49	3161	916	677	11457	1539	13673	13.2	7.8	12261	1.6	28.7	5544
11/17/75	12	323	146	7877	19	511	298	34	1885	547	323	9762	845	10930	10.1	8.8	10211	0.6	26.4	2152
11/24/75	12	441	148	11150	19	700	408	30	2019	585	365	11711	932	13008	6.0	9.4	7002	0.4	32.8	1452

* Pump off all of this week

APPENDIX B

WEEKLY SUMMARY
PILOT PLANT SOLIDS BALANCE
Johnson County, Kansas

DECEMBER & JANUARY

Week Ending	Softening Basin Solids Production										Produced Total Solids				Carbonator Inf. Total Solids			Thickener Eff. Total Solids		
	Turb.		Alk.		Raw Water			Recycled Magnesium			Turb.	$CaCO_3$	$Mg(OH)_2$	Total	Sludge gpm	% Dry Solids	lb/day	gpm	% Dry Solids	lb/day
	mg/l	lb/day	mg/l	lb/day	$CaCO_3$ mg/l	$CaCO_3$ lb/day	$Mg(OH)_2$ lb/day	$CaCO_3$ mg/l	$CaCO_3$ lb/day	$Mg(OH)_2$ lb/day	lb/day	lb/day	lb/day							
12/1/75	25	822	125	6839	12	394	230	27	1943	564	822	10802	794	12418	11.5	9.0	12413	4.1	10.7	9227
12/8/75	30	995	85	5292	18	482	281	20	1383	401	995	6675	682	8352	9.9	4.3	5162	5.1	9.9	5788
12/15/75	22	362	112	3746	27	448	261	25	820	238	362	4566	499	5427	9.6	7.3	8321	4.6	11.6	6611
12/22/75	31	517	99	3307	21	348	203	20	572	192	517	3970	395	5025	7.8	8.2	9882	1.2	21.9	1954
12/29/75	24	403	101	3355	15	249	145	9	291	84	403	3646	229	4278	7.1	8.7	7687	3.9	8.5	3915
1/5/76	16	317	113	3876	13	218	127	20	677	196	317	4552	323	5192	10.3	9.7	12038	2.6	10.6	

APPENDIX B

PILOT SCALE FLOTATION SUMMARY

(Page 1 of 2)

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS				COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$			% Recovery	
					Conc.	Feed	Tails		
1	1.53(a)	1.25	0.33	8.7	95.0	87.1	82.0	42.8%	2/11/75
2	3.6 (a)	12.6	0.6	9.0	94.8	87.5	96.5	13.0	2/12/75
3	8.1 (a)	31.2	2.8	8.95	95.1	87.2	85.1	22.9	2/13/75
4	7.6 (a) 3.8 (b)	40.0	2.4		98.5	94.8	68.3	91.2	2/14/75, #1 Cl
5	7.0 (a)	3.3	3.4	9.0	98.8	87.3	80.8	40.9	2/25/75
6	5.2 (a)	2.7	2.2	8.8	72.8	87.3	74.6	—	2/26/75
7	5.5 (a)	2.7	2.7	8.9	98.3	89.7	89.5	2.5	3/19/75
8	3.4 (a)	2.2	1.7	9.2	96.7	89.5	90.4	—	3/20/75
9	3.6 (a)	2.7	1.8	9.15	93.8	96.3	87.3	—	3/20/75
10	15.8 (a)	4.1	2.0	9.0	71.4	78.0	82.0	—	4/15/75
11	6.6 (a)	1.6	1.7	9.0	69.8	82.2	83.6	—	4/15/75
12	2.3 (a)	1.8	1.4	8.75	72.2	81.9	82.4	—	4/16/75
13	2.3 (a)	33.7 (KOH)	1.4	10.5	76.1	81.4	83.1	—	4/16/76
14	3.3 (a)	26.2 (KOH)	1.4	10.5	71.5	81.5	84.3	—	4/16/76

APPENDIX C

PILOT SCALE FLOTATION SUMMARY

(Page 2 of 2)

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS				COMMENTS
					% $CaCO_3$			% Recovery	
	Collector	Na_2CO_3	SiO_2		Conc.	Feed	Tails		
17	4.2 (a)	12.5	0	8.5	82.9	71.0	61.6	51.5%	8/27/75
18	4.6 (a)	16.3	0	8.6	81.7	71.0	67.2	30.2	8/27/75
19	2.2 (a)	6.6	2.5	8.9	80.5	82.7	82.5	——	9/22/75
20	2.5 (a)	8.3	1.0	9.0	80.5	81.5	80.9	——	9/23/75
21	2.5 (a)	0	1.0	8.1	80.8	81.5	81.3	——	9/23/75
22	2.5 (a)	0	1.0	8.3	81.0	81.5	81.6	——	9/23/75
23	7.8 (a)	11.8	0	9.15	95	80.6	56.8	73.4	12/16/75
24	6.1 (a)	11.6	0	9.2	94.2	80.9	58.5	73.1	12/16/75
25	11.6 (a)	14.6	0	9.22	94.2	79.0	53.7	74.5	12/16/75
26	9 (a)	10.8	1.6	9.5	96.7	94.1	76.0	82.9	1/12/76 4.8% Solids
27	4.3 (a)	7.7	1.7	9.3	99.4	95.7	77.5	86.3	1/13/76 6.7% Solids

(a) Dresinate 81
(b) Sodium Alkyl Sulfate

APPENDIX C

BENCH SCALE FLOTATION SUMMARY

Feed Grade - 86.3% $CaCO_3$

Date Collected - 2/24-27/75

Run #	REAGENT FEEDS (lb/ton) Collector	REAGENT FEEDS (lb/ton) Na_2CO_3	REAGENT FEEDS (lb/ton) SiO_2	pH	RESULTS % $CaCO_3$ Conc.	RESULTS % $CaCO_3$ Tails	RESULTS % Recovery	COMMENTS
2/24 1	1(b)	1	1	9.0	89.6	—	—	First Clnr.
2/24 2	2(b)	1	1	9.0	88.9			Rougher
2/24 3	2(b)	1	2	9.2	91.4	77.5		Rougher
2/24 4	2(b)	1	3	9.0	90.2	76.8		Rougher
2/25 1	2(g)	1	2	9.0	97.2	59.0	69.1	Second Clnr.
2/25 2	2(b)	1	2	9.0	97.8			Second Clnr.
2/27 1	2(b)	1	2	9.4	98.3	52.5		
2/27 2	2(b)	0	2	9.3	98.2	60.0		
2/27 3	2(b)	4	2	9.65	98.9	60.0		

(b) Dresinate 81
(g) Mixture Sodium Aklyl Sulfate and Dresinate

APPENDIX C

Feed Grade - 79.0% $CaCO_3$
Magnesium - 2.9 mg/g

BENCH SCALE FLOTATION SUMMARY

Date Collected - 2/28/75

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
1	2(b)	1	2	9.1	78.5	67.5		5% pulp First Clnr
2	2(b)	1	2	9.2	88.3	72.5		10% pulp Second Clnr
3	2(b)	1	2	9.1	96.8	72.5		15% pulp Second Clnr.

(b) Dresinate 81

APPENDIX C

Feed Grade - 91.8% $CaCO_3$

BENCH SCALE FLOTATION SUMMARY

Date Collected - 3/17-18/75

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
3/17 1	0.5(b)	1	2	9.45	97.4	89.7	28.9	Second Clnr.
3/17 2	4(b)	1	2	9.45	98.3	83.3	60.7	" "
3/17 3	2(b)	1	0.5	—	97.5	84.0	61.4	" "
3/17 4	2(b)	1	4	—	96.8	85.6	58.4	" "
3/18 1	0.5(g)	1	2	--	95.4	90.5		First Clnr.
3/18 2	4(g)	1	2	--	96.0	28.8	97.4	Second Clnr.

(b) Dresinate 81
(g) Mixture Sodium Alkyl Sulfate and Dresinate (1:1)

APPENDIX C

Feed Grade - 87.0% $CaCO_3$
Magnesium - 4.7 mg/g

BENCH SCALE FLOTATION SUMMARY

Date Collected - 4/14-16/75

Run #	REAGENT FEEDS (lb/ton) Collector			pH	RESULTS % $CaCO_3$ Conc.			COMMENTS
	Collector	Na_2CO_3	SiO_2		Conc.	Tails	% Recovery	
4/14 1	2.8(g)	2	2	9.20	76.4	79.8	--	No Selectivity
4/14 2	5.7(g)	2	2	9.35	91.6	68.1	85	
4/14 3	5(g)	2	2	9.33	76.3	79.3	--	No Selectivity
4/15 1	4 (b)	(f)	3	11.0	87.7	87.8		No Selectivity
4/16 1	4 (b)	(f)	3	11.0	79.8	75.4		No Selectivity

(b) Dresinate 81
(f) KOH used to adjust pH
(g) Mixture Dresinate TX60W and Sodium Alkyl Sulfate (1:1)

NOTE: Recycle of sludge was later suspected to be inoperative at this time.

APPENDIX C

Feed Grade - 78.4% $CaCO_3$

BENCH SCALE FLOTATION SUMMARY

Date Collected - 4/18/75

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
1	3(b)	(f)	1	10.8	78.2	77.9		No Selectivity
2	3(b)	(f)	3	10.9	73.4	79.9		No Selectivity
3	3(b)	(f)	1	9.1	77.8	78.0		No Selectivity
4	3(b)	(f)	3	9.0	74.2	81.2		No Selectivity
5	3(b)	(f)	1	11.0	78.4	79.4		No Selectivity
6	3(b)	(f)	0	11.0	77.5	80.0		No Selectivity
7	3(b)	(f)	0	9.0	78.5	76.7		No Selectivity

(b) Dresinate 81

(f) KOH was added

NOTE: High pH flotation was evaluated in an attempt to precipitate magnesium as $Mg(OH)_2$. Recycle of sludge was suspected of being inoperative at this time.

APPENDIX C

BENCH SCALE FLOTATION SUMMARY

Feed Grade - 86.7% $CaCO_3$
Magnesium - 5.3 mg/g

Date Collected - 5/13-14/75

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
5/13 1	8(d), 2(b)	0	0	8.5	85.9	86.2		No Selectivity
5/13 2	2(b)	0	0	8.5	85.1	86.2		No Selectivity
5/13 3	9(d)	0(f)	0	11.1	83.1	85.1		No Selectivity
5/13 4	2(d)	0	0	11.1	84.8	85.8		No Selectivity
5/14 1	1(b) 2(d)			9.0	86.3	84.6		No Selectivity
5/14 6	1(b) 6(d)	0	0	9.0	84.5	84.7		No Selectivity
	(Total of 40 Tests)							

(b) Dresinate 81
(d) Palomyn
(f) KOH used to adjust pH

NOTE: Forty (40) bench scale flotation tests were performed using various combinations of Palomyn, a relatively pure oleic acid, and Dresinate. Palomyn showed no additional selectivity with poor frothing. Any added frother was of no benefit

APPENDIX C

Particle Size in Microns					Cu
Max.	Min.	D_{85}	D_{60}	D_{10}	
20	0.8	5.6	5.0	1.5	3.33

BENCH SCALE FLOTATION SUMMARY

Feed Grade - 86.5% $CaCO_3$
Magnesium - 5.8 mg/g

Date Collected - 6/10/75

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
1	3(a)	2	2	8.7	84.5	--	--	Tests 1 through 5, #1 Cleaner only
2	2(a) 1(d)	1	0	8.6	85.4	--	--	--
3	3(a)	2	1	8.7	86.3	--	--	Washed
4	2(a)	2	1	9.0	86.0	--	--	Acidified to pH 6.5, decant
5	2(a)	3	1	9.0	90.2	--	--	Acidified to pH 6.5, vacuum filtered

(a) Dresinate 81
(d) Pamolyn

APPENDIX C

BENCH SCALE FLOTATION SUMMARY

Feed Grade - 11.1% $CaCO_3$
Magnesium - 6.2 mg/g

Date Collected - 7/3/75

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
1	4(a)	2	2	9	69.1	--	--	Acidified decant
2	3(a)	2	2	9	69.1	--	--	Scrub, decant twice

(a) Dresinate 81

APPENDIX C

BENCH SCALE FLOTATION SUMMARY

Feed Grade - 71.8% $CaCO_3$
Magnesium - 5.0 mg/g

Date Collected - 8/27/75

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
1	3(a)	75	2.0	9.0	81.0	69.9	19.3	
2	3(a)	75	0.0	9.0	74.3	—	—	Ro only tests 2-15
3	5(a)	75	0.0	9.0	75.5	—	—	
4	3(a)	75	2.0	9.0	73.4	—	—	
5	5(a)	75	2.0	9.0	69.0	—	—	
6	7(a)	75	2.0	9.0	74.4	—	—	
7	3(a)	w/HCl	2.0	7.0	71.0	—	—	
8	3(a)	w/HCl	2.0	8.0	73.5	—	—	
9	3(a)	75	2.0	9.0	70.7	—	—	
10	3(a)	95	2.0	10.0	70.9	—	—	
11	3(a)	75	2.0	9.0	76.5	—	—	Temp. - 35°C
12	3(a)	--	0.0	7.8	72.7	—	—	
13	3(a)	0.75 $Ca(OH)_2$	0.0	8.0	76.0	—	—	
14	3(a)	2.6 $Ca(OH)_2$	0.0	9.0	75.0	—	—	
15	3(a)	4.9 $Ca(OH)_2$	0.0	9.0	73.6			
16	3(a)	0	2	7.8	78.1	—	—	Ro only tests 16-22
17	3(a)	4.0 $Ca(OH)_2$	2	9.0	71.8	—	—	
18	3(a)	0	2	8.2	76.7	—	—	Scrub, Pressure filtered
19	3(a)	0	0	8.2	79.9	—	—	
20	3(a)	1.9	0	8.5	82.4	—	—	
21	3(a)	2.6 $Ca(OH)_2$	0	9.0	82.4	—	—	
22	3(a)	2.6 $Ca(OH)_2$	2	9.0	82.3	—	—	

(a) Dresinate 81

APPENDIX C

Feed Grade - 82.7% $CaCO_3$
Magnesium - 5.0 mg/g

BENCH SCALE FLOTATION SUMMARY

Date Collected - 9/22/75

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
1	3(a)	4	2	9	83.0	80.7	87.3	Ro only tests 1-5
2	3(a)	4	2	9	84.5	79.3	66.8	Scrub, pressure filter
3	3(a)	4	2	9	82.9	81.0	94.6	Temp. 36°C
4	3(a)	7	2	9	84.4	78.6	72.1	Acidify, pressure filter
5	4(a)	w/HCl	2	7.5	81.9	--	--	
6	3(a)	4	2	9	87.7	79.9	38.1	Scrub, pressure filter
7	3(a)	4	2	9	88.8	79.5	36.9	" "
8	3(a)	--	2	7.5	90.0	77.3	46.3	" "
9	3(a)	4	0	9	88.6	80.1	32.8	

(a) Dresinate 81

APPENDIX C

Particle Size in Microns					Cu
Max.	Min.	D_{65}	D_{60}	D_{10}	
40	1.5	15.5	14.4	4.4	3.27

BENCH SCALE FLOTATION SUMMARY

Date Collected - 10/8/75

Feed Grade - 88.3% $CaCO_3$
Magnesium - 7.9 mg/g

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
1	1.9(b)	3.3	1.0	9.0	96.8	73.3	70.0	
2	2.8(b)	3.3	1.0	9.0	97.2	70.4	73.5	
3	3.8(b)	3.3	1.0	9.0	96.6	61.3	83.7	
4	2.8(b)	3.3	2.8	9.0	96.9	70.4	74.1	
5	2.3(b)	3.3	0.0	9.0	96.7	65.6	79.9	
6	2.8(b)	3.3	1.0	9.0	96.1	64.0	82.4	+1.0 lb/ton
7	2.8(b)	0.0	1.0	7.0	96.9	86.7	17.2	pH adjusted w/HCl (d)
8	2.8(b)	0.0	1.0	8.0	96.6	74.7	67.9	" "
9	0.5(b)	3.3	1.0	9.0	---	88.3	0.0	
10	1.0(b)	3.3	1.0	9.0	97.1	85.9	23.6	
11	4.7(b)	3.3	1.0	9.0	96.7	57.1	86.3	
12	5.7(b)	3.3	1.0	9.0	95.8	50.0	90.7	
13	2.8(b)	3.3	0.0	9.0	97.0	68.4	76.4	
14	2.8(b)	3.3	0.5	9.0	96.7	67.3	78.2	
15	2.8(b)	3.3	3.7	9.0	96.8	65.3	80.0	
16	2.8(b)	3.3	4.5	9.0	97.2	67.4	77.2	
17	2.8(b)	4.6	1.0	9.5	97.1	63.1	81.5	
18	2.8(b)	5.1	1.0	10.0	97.6	72.5	69.6	
19	2.8(b)	3.3	1.0	9.0	#3-97.4	67.4	76.8	
					#2-96.9	63.0	83.1	
					#1-96.0	59.4	85.8	
					Ro-92.8	54.5	92.7	

(b) Dresinate TX60W; (d) Palcoyn

APPENDIX C

BENCH SCALE FLOTATION SUMMARY

Feed Grade - 91.9% $CaCO_3$
Magnesium - 6.3 mg/g

Date Collected - 10/8/75

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
1	3(a)	4.0	0.2	9.0	92.0	91.6	75.1	RO only tests 1-11
2	3(a)	4.0	0.0	9.0	93.3	89.0	68.5	
3	3(a)	4.0	0.2	9.0	92.9	92.1	75.2	Scrub, pressure filtered 92.7% $CaCO_3$
4	3(a)	1.9 $Ca(OH)_2$	0.0	9.0	92.5	90.8	65.1	
5	3(a)	1.9 $Ca(OH)_2$	0.0	9.0	92.7	90.2	68.6	
6	3(a), 3(e)	0.3 $Ca(OH)_2$	0.5	9.0	92.7	90.7	60.5	
7	3(a), 3(e)	0.3 $Ca(OH)_2$	0.0	9.0	93.3	89.7	62.0	
8	3(a), 3(e)	0.15 $Ca(OH)_2$	0.0	9.0	93.5	88.9	85.4	Scrub, pressure filtered 92.8% $CaCO_3$
9	3(b)	0.15 $Ca(OH)_2$	0.0	9.0	93.5	90.7	43.6	
10	3(b), 3(e)	0.15 $Ca(OH)_2$	0.0	9.0	92.0	90.7	42.9	
11	5(b), 5(e)	0.15 $Ca(OH)_2$	0.5	9.0	91.6	86.7	—	
12	7(b), 3.7(d)	2.0	1.5	9.5	93.3	—	45.3	Scrub, pressure filtered
13	8(b), 3.7(d)	2.0	1.4	9.54	94.0	—	54.5	Scrub, pressure filtered
14	6(b) 3.1 (d)	2.0	1.5	9.5	94.6	—	39.8	Slurry, decant twice
15	6(b) 3.1(d)	3.0	1.5	9.4	93.3	—	61.7	Ion Exchange Resin 3.5 g Amberlite 120, 150 min.
16	7(b) 3.1(d)	1.0	1.0	9.54	94.3	—	43.5	NaCl Scrub, Pressure Fil.

(a) Dresinate 81; (b) Dresinate TX60M; (d) Pamolyn; (e) Sodium Alkyl Sulfate

APPENDIX C

Particle Size in Microns					Cu
Max.	Min.	D_{65}	D_{60}	D_{10}	
25	1.6	8.2	7.8	3.75	2.06

BENCH SCALE FLOTATION SUMMARY

Feed Grade - 94.6% $CaCO_3$
Magnesium - 6.3 mg/g

Date Collected - 10/30/75

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
1	7(b) 2.3(d)	6	1.5	9.1	96.0	89.2	72.7	One Cleaner
2	4(b) 3(e) 2.3(d)	4	1.0	9.0	96.3	92.0	61.6	" "
3	5(b) 1.2(d)	4	1.5	9.4	95.9	90.1	78.7	Scrub Pressure filter
4	4(b) 0.9(d)	1.5	1.5	9.15	95.2	90.0	94.5	"

(b) Dresinate TX60W; (d) Pamolyn; (e) Sodium Alkyl Sulfate

APPENDIX C

Feed Grade - 96.1% $CaCO_3$
Magnesium - 15.2 mg/g

BENCH SCALE FLOTATION SUMMARY

DATE COLLECTED - 10/30/75

Particle Size in Microns					Cu
Max.	Min.	D_{65}	D_{60}	D_{10}	
65	2.85	18.2	17	6.7	2.54

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
1	4(b) 1.4(d)	5	1.0	9.03	97.8	78.4	94.1	Carbonated, pressure filtered 96.4% $CaCO_3$; 11 mg/g Mg; #1 Cl only
2	4(b)	1	2.5	9.3	97.4	89.9	83.8	
3	4(b)	1	2.5	9.35	97.7	85.9	87.9	Scrub, pressure filtered
4	3(b) 1.7(d)	1	3.5	9.35	98.1	84.0	87.6	" "

(b) Dresinate TX60W
(d) Sodium Alkyl Sulfate

APPENDIX C

Particle Size in Microns					Cu
Max.	Min.	D_{85}	D_{60}	D_{10}	
33	1	14.5	13.8	4.85	2.85

BENCH SCALE FLOTATION SUMMARY

Feed Grade - 92.3% $CaCO_3$
Magnesium - 6.0 mg/g

Date Collected - 11/17/75

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
1	3(b)	3.5	0.0	9.0	96.0	93.1	35.2	Feed 94.1, tests 1, 2
2	5(b)	3.5	0.0	9.0	97.3	87.9	68.2	
3	6(b)	3.5	0.5	9.0	95.7	82.7	76.7	Feed 92.3
4	6(a)	3.5	0.5	9.0	95.1	90.6	38.9	
5	2.4(b)	6	0.7	9.3	93.0	—	49.8	Feed 90.4
6	2.4(b)	4	0.7	9.6	93.2	—	35.9	
7	5(b)	12	1.0	9.4	93.7	—	60.0	3 Clnrs tests 7-13
8	5(b)	10	1.0	9.5	94.7	—	65.1	
9	5(b)	10	0.0	9.5	94.9	—	43.6	
10	5(b)	10	0.0	9.7	95.1	—	68.6	
11	5(b)	23	1.0	9.7	94.0	—	86.0	
12	5(b)	23	0.0	9.6	93.8	—	85.6	
13	5(b)	12	1.0	9.3	94.2	—	82.6	

(a) Dresinate 81; (b) Dresinate TX60W

APPENDIX C

Particle Size in Microns					Cu
Max.	Min.	D_{55}	D_{50}	D_{10}	
33	1	14.5	13.8	4.85	2.85

Feed Grade - 86.3% $CaCO_3$
Magnesium - 3.0 mg/g

BENCH SCALE FLOTATION SUMMARY

Date Collected - 12/15/75

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
1	4(b)	3.0	0.5	9.1	98.2	44.2	88.7	
2	4(a)	3.0	0.5	9.1	97.5	38.6	91.5	
3	4(c)	3.0	0.5	9.1	98.6	64.5	73.0	
4	1(b)	3.5	0.5	9.0	98.9	67.1	69.2	
5	3(b)	3.5	0.5	9.0	97.7	46.6	88.0	
6	5(b)	3.5	0.5	9.0	97.6	42.0	90.1	
7	8(b)	3.5	0.5	9.0	97.2	36.2	92.5	
8	5(b)	3.5	2.0	9.0	98.5	46.3	87.5	
9	5(b)	3.5	0.0	9.0	97.3	38.6	91.6	
10	5(c)	3.5	0.5	9.0	98.9	53.8	82.6	
11	5(a)	3.5	0.5	9.0	97.9	38.8	91.2	
12	3(c)	3.5	0.5	9.0	99.1	76.7	49.2	
13	3(a)	3.5	0.5	9.0	97.9	44.7	88.7	
14	3(b)	3.5	0.5	9.0	93.5	77.4	60.0	Temp. - 35°C
15	5(b)	3.5	0.5	9.0	94.1	83.7	27.3	Temp. - 35°C
16	5(b)	3.5	0.5	9.0 - 6.6	83.4	85.4	—	Float with CO_2
17	5(b)	3.5	0.5	9.0	98.3	53.5	83.4	5% solids pulp
18	5(b)	3.5	0.5	9.0	98.4	36.1	91.9	10% solids pulp
19	5(b)	3.5	0.5	9.0	97.8	34.4	92.9	15% solids pulp
20	5(b)	3.5	0.5	9.0	95.6	36.1	93.5	20% solids pulp
21	5(b)	17.0	0.5	9.0	97.6	57.6	81.1	3.2 mg/g Mg
22	5(b)	40.0	0.5	9.0	97.6	63.5	75.6	8.8 mg/g Mg
23	5(b)	80.0	0.5	9.0	100.0	67.7	66.7	14.4 mg/g Mg
24	5(b)	145.0	0.5	9.0	97.7	76.8	51.5	19.1 mg/g Mg
25	7(c)	3.5	0.5	9.0	98.1	54.7	82.8	
26	12(c)	3.5	0.5	9.0	97.6	46.9	87.9	
27	5(b)	3.5	0.0	9.1				
28	5(b)	3.5	3.0	9.1				
29	5(b)	3.5	0.0	9.1				Temp.- 27°C
30	5(b)	3.5	3.0	9.1				Temp. - 27°C
31	5(b)	3.5	0.0	9.1				Temp. - 35°C
32	5(b)	3.5	3.0	9.1				Temp. - 35°C

(a) Dresinate 81; (b) Dresinate TX60W; (c) Dresinate D860W

APPENDIX C

Feed Grade - 94.9% $CaCO_3$

BENCH SCALE FLOTATION SUMMARY

Date Collected - 12/17/75

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$		% Recovery	
					Conc.	Tails		
1	5.2(b)	3.8	0.5	9.4	98.3	71.7	90.3	
2	2.6(b)	1.3	0.0	9.1	98.8	80.7	81.7	
3	4(b)	1.9	0.5	9.1	99.7	67.2	86.8	Carbonated pressure filtered 93.7% $CaCO_3$

(b) Dresinate TX60W

APPENDIX C

Feed Grade - 65.0% $CaCO_3$
Magnesium - 6.5 mg/g

BENCH SCALE FLOTATION SUMMARY

Date Collected - 4/28/76

Run #	REAGENT FEEDS (lb/ton)			pH	RESULTS			COMMENTS
	Collector	Na_2CO_3	SiO_2		% $CaCO_3$ Conc.	% $CaCO_3$ Tails	% Recovery	
1	2.5	6	0	9.0	86.6	—		Third Clnr
2	2.5	6	1	9.0	85.2	--		" "
3	5.0	4	0	9.0	86.2	35.3	77	" "
4	5.0	5	0	9.0	78.6	44.8	72	" "
5	5.0	5	2	9.0	81.3	37.3	78	" "
6	5.0	5	0	9.0	79.1	42.8	74	Second Clnr
7	7.0	7	1	9.0	85.4	36.7	73	Third Clnr
8	7.0	6	2	9.0	83.9	38.5	75	Second Clnr
9	7.0	6	4	9.0	87.1	40.8	70	Second Clnr
10	7.0	6	0	9.0	92.0	44.3	61	Fourth Clnr
11	7.0	6	2	9.0	92.2	55.5	37	Fourth Clnr
12	7	6	4	9.0	92.0	50.1	50	Fourth Clnr

NOTE: Carbonated pressure filtered accelator sludge

All Runs Dresinate TX-60W

APPENDIX C

APPENDIX D

CONVENTIONAL SLUDGE DEWATERING LAGOON

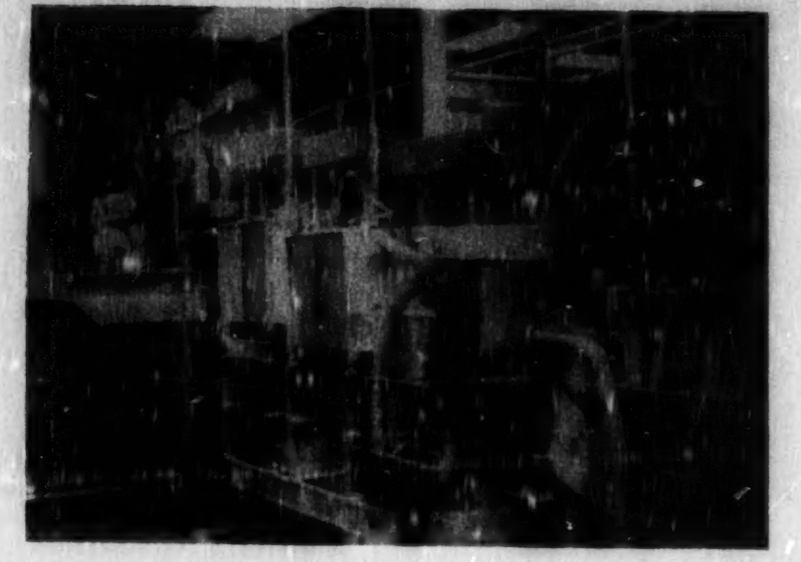
PILOT EQUIPMENT
INCLUDING PRECIPITATOR, THICKENER,
PRODUCT STORAGE, AND SLUDGE HANDLING BUILDING

APPENDIX D

CARBONATION OF SOFTENING SLUDGE USING 18% CO_2

VACUUM FILTRATION OF CARBONATED SLUDGE

APPENDIX D



PILOT FLOTATION CIRCUIT

FROTH OVERFLOW, CALCIUM CARBONATE FLOTATION

GLOSSARY OF FLOTATION TERMS

activator: A reagent which increases the flotation activity and aids flotation of a mineral or minerals.

beneficiation: Improvement of the mineral purity of a pulp; removal of impurities from a valuable mineral thereby increasing its value and suitability for use.

calcite: The predominant mineral form, crystalline in structure, of calcium carbonate.

cleaners: Sequential flotation steps, in addition to the rougher, to further purify concentrates.

collector: A substance which when added to the mineral pulp attaches to, coats, or is adsorbed by normally nonfloating minerals making them capable of adhering to gas bubbles.

concentrates: Flotation products of improved purity containing a minimum amount of impurities.

depressant: A reagent which lowers the flotation activity and suppresses or prevents flotation of a mineral or minerals.

fatty acid: An organic compound consisting of the carboxyl radical - COOH, and an alkyl (non-cyclic hydrocarbon) or aryl (cyclic hydrocarbon) radical, usually represented by R.

flotation circuit: An arrangement or sequence of flotation steps designed to optimize the separation of impurities from valuable mineral.

froth: A formation on the water surface of gas bubbles, pulp liquor, collected mineral and a certain amount of uncollected but entrapped mineral, resulting from the rise to the surface of dispersed bubbles.

froth flotation: A process for separating finely divided solids from each other in a water suspension, resulting from the adhesion of some species of solids to generated or introduced gas bubbles and the simultaneous adhesion of other species of solids to water.

frother: Generally organic substances which, when added to water, lower the surface tension and cause the formation of foam on the water surface upon introduction of gas bubbles.

grade: The relative purity (normally in percent) of a flotation product; the percentage of a flotation product which consists of valuable mineral.

limestone: The predominant mineral rock containing calcium carbonate.

modifier: An additional flotation agent added to modulate the action of collectors and to obtain the most effective control.

pulp: Finely divided solids in a water suspension.

recovery: The percentage of valuable mineral present initially which is now available in purified form.

rougher: The initial flotation step in which the bulk of separation is formed.

selectivity: Measure of the ability of a collector or modifier to affect the floatability of only a specific mineral or group of minerals.

tailings: Flotation products to be discarded containing the majority of impurities and a minimum of valuable mineral.